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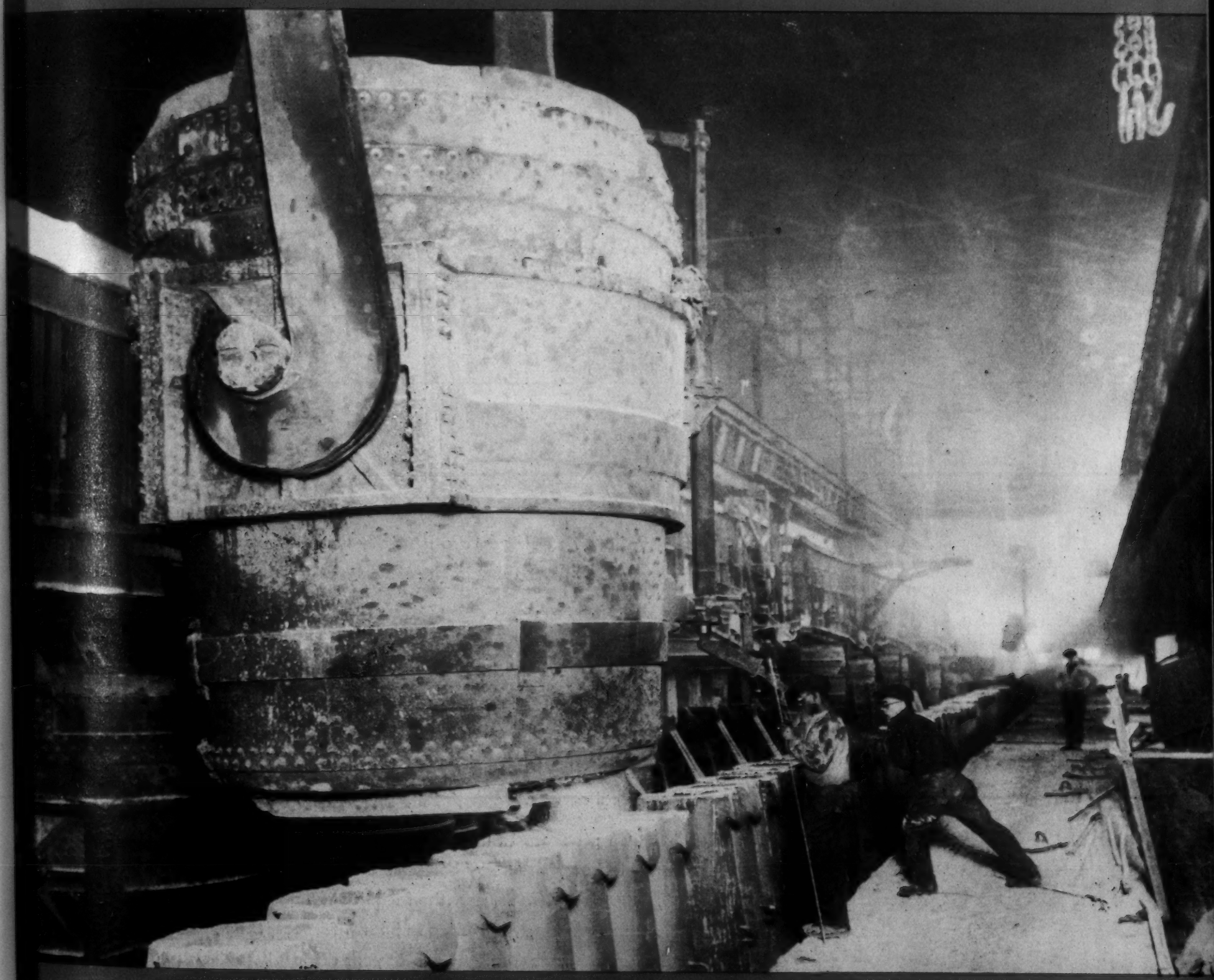
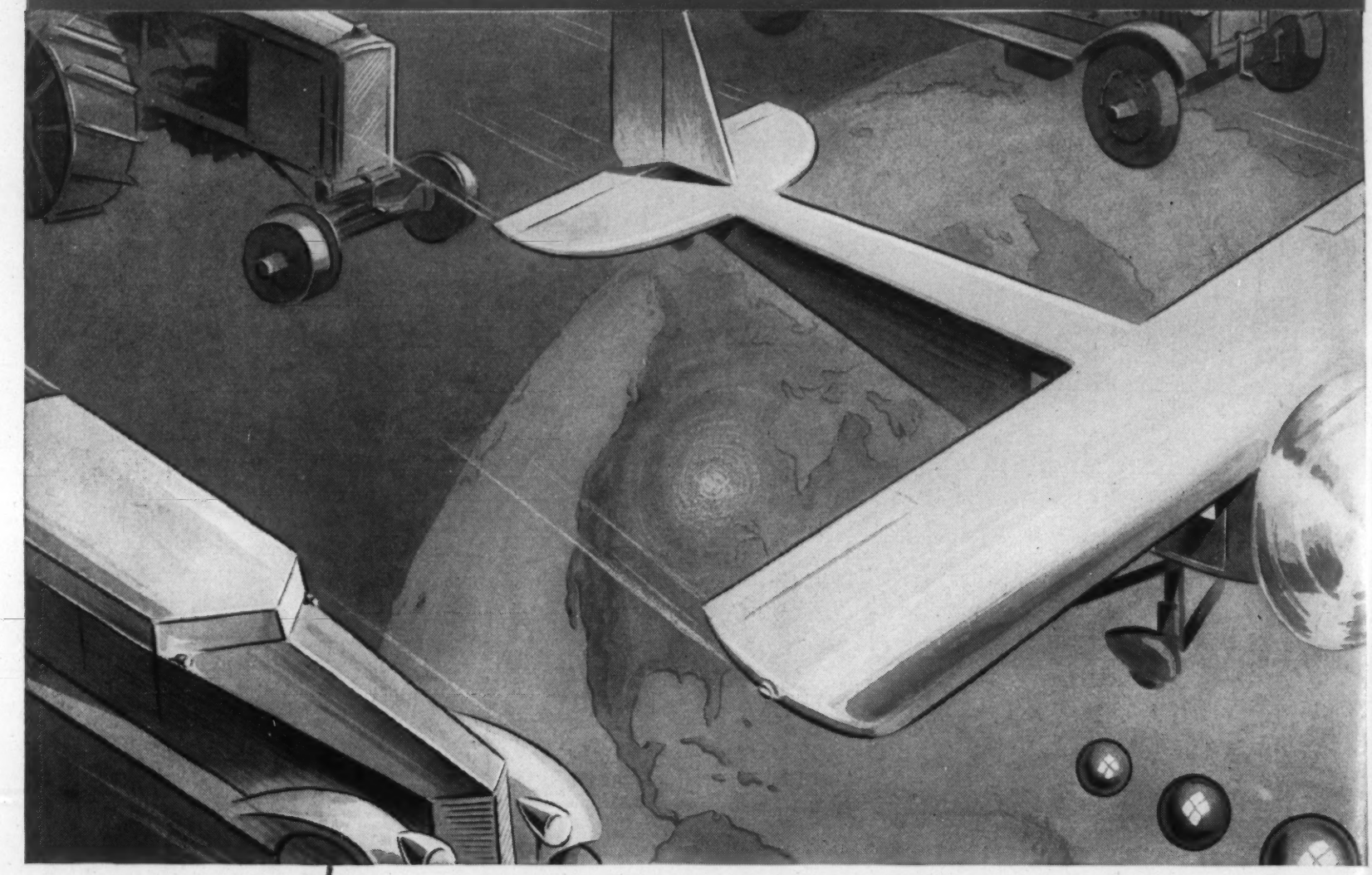
INCLUDING
CURRENT METALLURGICAL ABSTRACTS

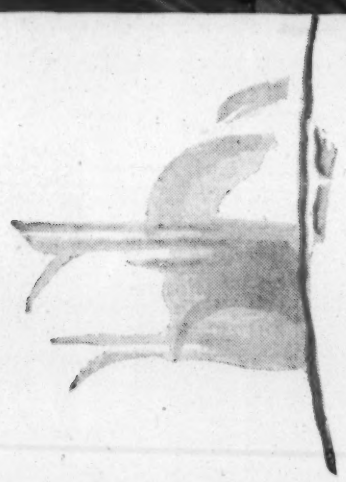


TEEMING AN OPEN HEARTH HEAT AT LACKAWANNA PLANT, BETHLEHEM STEEL COMPANY

VOLUME 4 **MARCH 1933** NUMBER 3

WHAT "WORLD'S LARGEST" MEANS TO YOU





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EDITORIAL COMMENT

Strength and Beauty

MOST metallurgical engineers and practically all teachers and text books of metallurgy are inclined to appraise metals and alloys in terms of brute strength. In bridges and sky scrapers, in heavy machinery, in machine tools, in railway service, in motor vehicles and in agricultural implements, strength, ease of forming and machining, and price are the main factors. These factors, with strength on the strength-weight basis, are paramount in aircraft.

High temperature strength is involved in furnace parts, and in the oil and steam power industries. Where moving parts are concerned, questions of wear resistance come in, and under corrosive conditions, resistance to corrosion. In the paper and textile industries, corrosion is often far more important than any other property.

Many years of experience have built up acceptable methods of testing to evaluate metals for static, impact, and fatigue strength. Methods for high temperature testing are slowly being developed. The requirements for evaluation of wear-resistance and corrosion-resistance are not so well worked out. When he gets off the beaten path of strength-testing, the testing engineer is often at a loss. Specifications for bearing metals so far scarcely evaluate any of the properties that are really important in bearings.

Yet there are myriads of applications of metals in which brute strength is of little or no importance, and a rather weak material, as alloys go, will serve excellently. Choice then depends on other factors. Die castings have risen to great importance, not because of strength but because of the ease and cheapness with which they can be produced to dimensions. Compressed, powdered metal objects may some day be in a similar category. Deep-drawing stock is evaluated not for its strength, but for its formability. We have cast iron cam shafts, and cast iron crank shafts appear to be on their way, not because of greater strength than forged steel, but because they combine sufficient strength with ease of manufacture. Malleable iron holds its place not primarily because of its fair strength but largely because of its ready machineability.

Although weldability, machineability and ability for deep-drawing are not readily evaluated in quantitative fashion, the metallurgical engineer considers that the products that must be rated on those properties are still within his domain because of their large tonnage. Metals in tonnage use for electrical equipment in which conductivity and magnetic properties are vital are also considered in his field, though perhaps on the border-line. When other properties than strength take the spot-light, the average metallurgical engineer seems to be interested only when there is a large tonnage of the product.

When it comes to uses in which properties like electron emission are involved, as in the vacuum tube industry, he generally figures that such things are over his head and leaves them to the physicist.

When strength is minor and appearance is all-important, the regulation ferrous metallurgist is all at sea. He is inclined to leave electroplating to the chemist. Some few metallurgists are interested in enameling stock, but on the whole, metallurgists are not greatly interested in aesthetic or decorative applications of metals.

Yet decorative properties are strictly utilitarian, because they lead to new uses. There is nothing decorative about ordinary steel, especially in the rusted condition. As long as metallurgical thought and instruction is confined to matters of brute strength on tonnage products, we will breed metallurgists who pass up opportunities for extended use of metals through their beautification. Makers of stainless steel, aluminum, copper and copper alloys are very much concerned with methods of polishing, etching, coloring of the surface and so on, that add to the decorative possibilities for architectural and household purposes. But what course in metallurgy attempts to give that point of view to the students?

The ability of a given alloy to take a distinctive and attractive surface finish might lead to some new and very extended use of that particular alloy.

Any especial property or combination of properties of a material may lead to new uses. The reflectivity of a bright aluminum surface has led to important uses of aluminum foil in building and refrigerator insulation.

Dental alloys are scarcely in tonnage use, but are extremely important. Dentists and dental schools are becoming metallurgically minded and producers of platinum metals are beginning to be interested in the dental field. Jewelry production is essentially a metal industry, but, with a few notable exceptions, metallurgists know little about the alloys used, though some of the precious metal alloys transcend more common alloys in theoretical interest, and ought to get more attention from the university groups.

The horological industry involves much interesting metallurgy, which is a closed book to most metallurgists. The lead industry knows about precipitation-hardened shot for shotgun shells, but the average metallurgist who is interested in precipitation-hardening probably does not.

There is ample reason for the metallurgical engineer to consider esthetics as well as brute strength, and to concern himself with properties of metals and alloys other than those found in the usual specifications.—H. W. GILLETT

(Continued on page 30)

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MUCH research work in metallurgy tends to bring out the need for increased refinements in, and cost of, testing and inspection in order to secure reliable material for severe engineering service. This article, however, shows that for low temperature service a variety of alloy steels and light alloys tend to have better rather than worse, properties, so that room temperature tests are adequate to establish the quality of the materials. While the toughness and resistance to impact of plain carbon steels (especially when cold-worked*) may drop off rapidly at subnormal temperatures, it is increasingly evident that, in the cases where low-temperature tests are required, simple and inexpensive tests, such as the impact and hole-tensile or similar tests, will suffice. Thanks to such work as this at Wright Field, other metallurgical laboratories will be spared the expense of rigging up cold rooms and other testing engineers of providing clothing suitable for a North Pole trip in order to evaluate the metals they study. Besides the relief one feels that the average metallurgical engineer need not worry much about low temperature effects upon his own product, it is a comfort to realize that work of this type is being carried on to make certain that aircraft travel will be as safe as it is speedy.

*S. Epstein. Embrittlement of Hot Galvanized Structural Steel. *Proceedings American Society for Testing Materials*, Vol. 32, Part 2, 1932, pages 293-379.

J. B. Johnson

Mechanical Properties at Minus 40 Degrees of Metals Used in Aircraft Construction*

By J. B. JOHNSON† and TURE OBERG‡

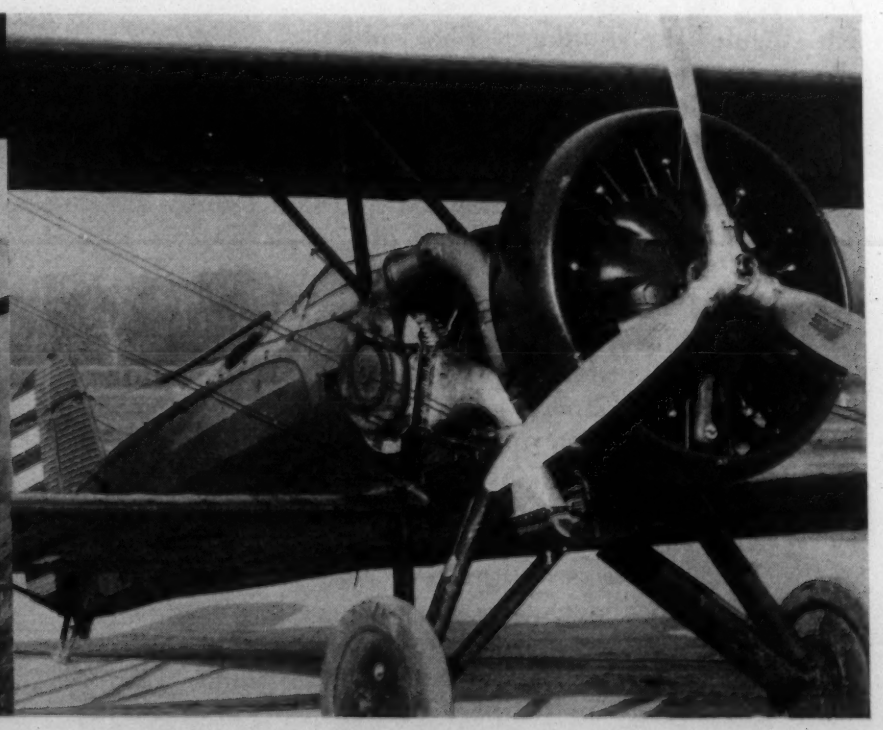
Ture Oberg

AIRCRAFT operates at temperatures below those which exist ordinarily in laboratories where the properties of materials are investigated. Factors of safety used in design are invariably based on the mechanical properties at a normal atmospheric temperature of approximately 25°C. It is desirable to find out whether this is a safe procedure. For this purpose the U. S. Army Air Corps has installed a cold chamber at Wright Field in which the atmosphere is maintained at a sub-normal temperature. It is not absolutely constant, but fluctuates between −40°C. (−40°F.) and −43°C. (−45½°F.). The temperature of −40°C. indicates an altitude of about 30,000 feet. This temperature was selected as it could be conveniently obtained and held for long periods and personnel making the tests are not subjected to undue discomfort. The results obtained by several investigators indicate that the greatest change in mechanical properties at low temperatures occurs between + 20° and −40°C. and that below −40° the rate of change is much less. Sergeson[1] gives one series of impact tests on nickel-molybdenum steel in which a rapid decrease occurs at approximately −45°C. but this is exceptional.

The cold chamber, shown in Fig. A, consists of a room containing approximately 800 cubic feet. The low temperature is obtained with a commercial 2-stage compressor using carbon dioxide as a refrigerant. The cooling coils are inclosed in a bunker with openings into the main chamber. Forced circulation is obtained by a

*Published by permission of Chief of Air Corps, U. S. Army.
†Chief, Material Branch, Wright Field, Dayton, Ohio.
‡Material Testing Engineer, Wright Field, Dayton, Ohio.

Paraphernalia used for High Altitude Testing with airplane in background.



High Altitude Pursuit Plane with Turbo Supercharger for obtaining full power at 20,000 feet.

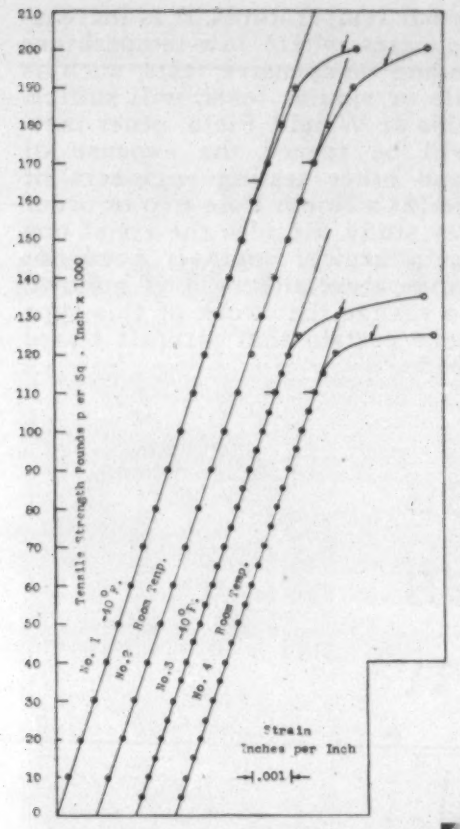


Fig. 1. Stress-Strain Chart of Iron base alloy. Chrome-Molybdenum Steel No. 1 (Tables I to III). Curves 1 and 2, Quenched in oil, drawn at 650°F. Curves 3 and 4, Quenched in oil, drawn at 1100°F.

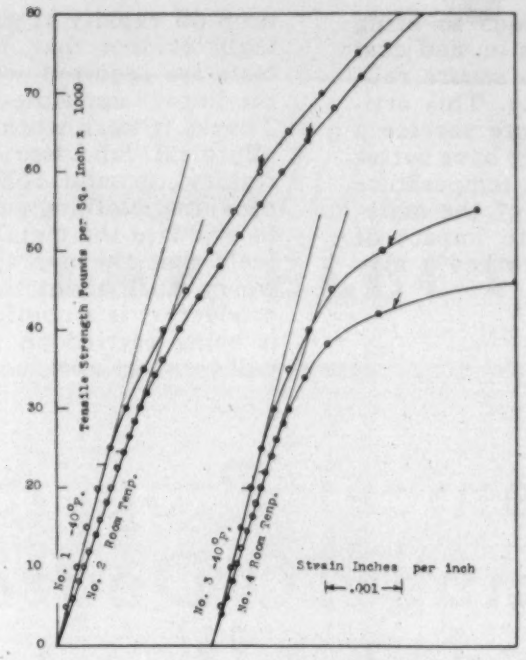


Fig. 2. Stress-Strain Chart of Iron base alloy. Chrome-Nickel Steel (18:8) No. 7 (Tables I to III). Curves 1 and 2, Cold rolled. Curves 3 and 4, Annealed.

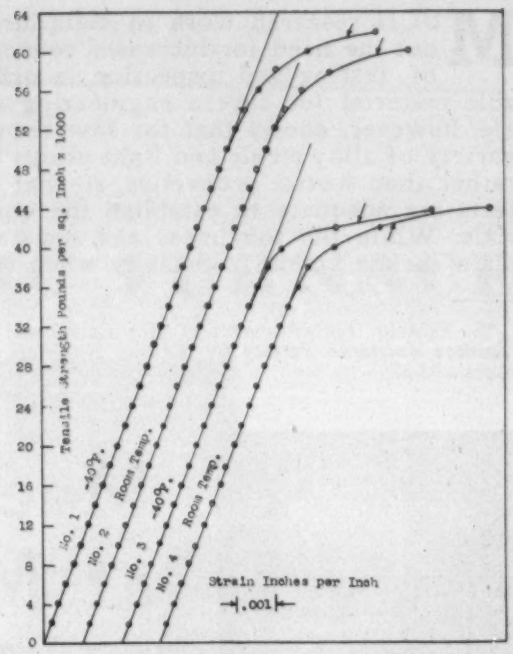


Fig. 3. Stress-Strain Chart of Aluminum base alloy. Aluminum Alloy Nos. 2 and 3 (Tables I to III). Curves 1 and 2, Alloy No. 3. Curves 3 and 4, Alloy No. 2.

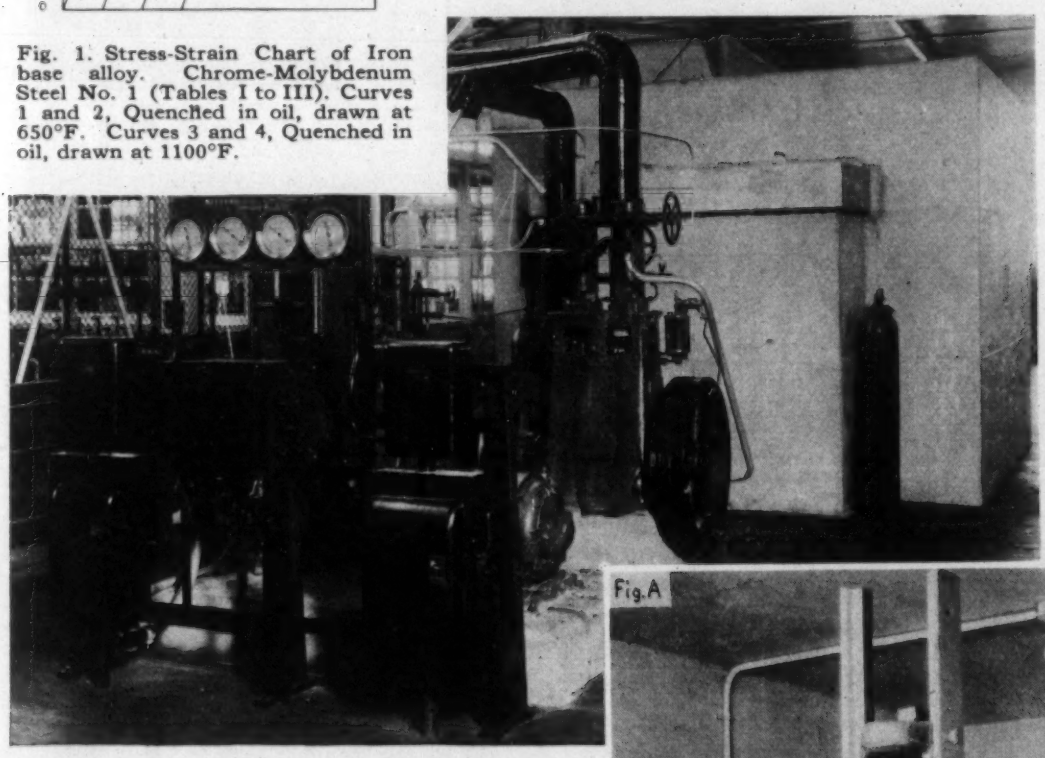
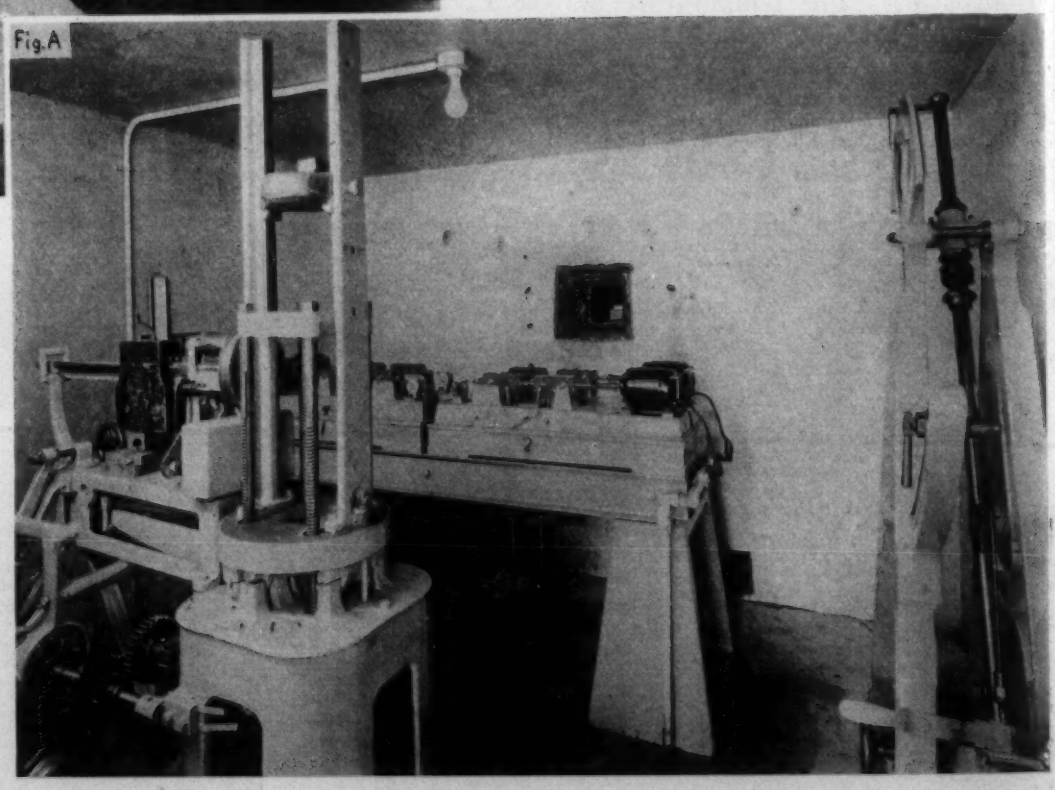


Fig. A



fan inside the bunker. The cold chamber can be shut off from the bunker so that the coils may be defrosted with practically no change in temperature in the chamber. The temperature has been maintained for periods of 3 to 4 months without difficulty.

Four R. R. Moore rotating beam fatigue machines, an Izod impact tester, Brinell hardness tester and a 20,000 lb. Olsen Universal Testing Machine are installed in the room. The machines are lubricated with a mixture of kerosene and low viscosity refrigerating machine oil. The tensile machine was calibrated at −42°C. All specimens are kept in the room overnight. The tensile specimens are mounted in the machine and the extensometer applied to avoid any slight change in temperature due to handling just before testing. The fatigue specimen operates at a higher temperature than the surrounding air due to the conduction of heat from the bearings and heat generated by internal fricture. The exact temperature will depend upon the load applied to the specimen and varies from −20° to −25°C. The temperatures were determined from the melting points of liquids which were placed in holes bored in the middle of the specimen.

Fatigue specimens run at normal room temperature are 20° to 40° hotter than the surrounding air temperature.

Tensile specimens had a gage length 2 inches by 0.500 inch in diameter, except in case of insufficient stock a proportional specimen was used with a gage length equal to the diameter multiplied by 4. The propeller forgings are tapered from a diameter approximately 6 inches to ½ inch. Specimens were selected ap-

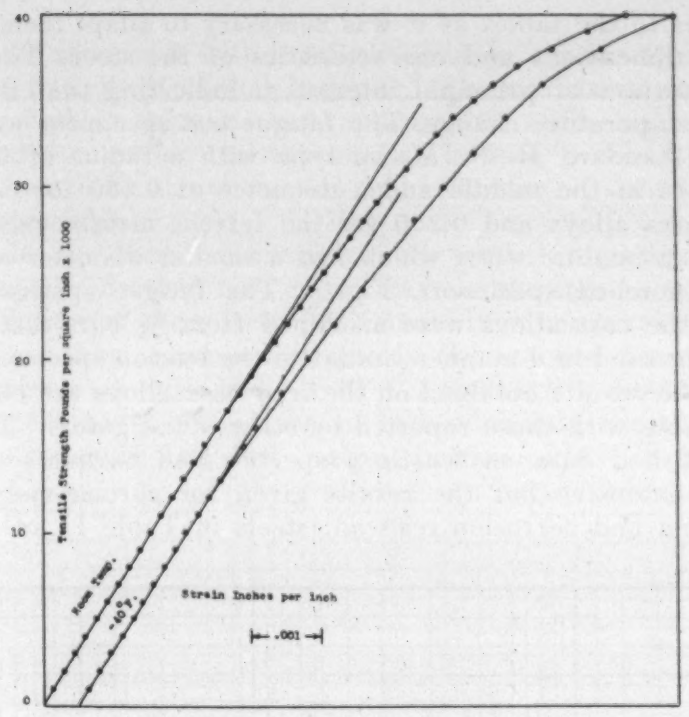


Fig. 4. Stress-Strain Chart of Magnesium base alloy. Magnesium Forging No. 12 (Tables I to III).

TABLE I. CHEMICAL COMPOSITION

Iron Base Alloys

No.	Fe[1]	C	Mn	P	S	Si	Cr	Ni	Mo
1	98	0.31	0.65	0.03[2]	0.03[2]	0.20	0.69		0.22
2	99	0.28	0.67	0.04[2]	0.025				
3	71	0.11	0.41	0.03[2]	0.03[2]	0.51	18.4	9.6	
4		0.12					18.8	8.4	
5	72	0.13	0.54	0.02	0.02	0.18	18.6	8.5	
6	72	0.08	0.31	0.04[2]	0.021	0.31	18.3	8.5	
7	74	0.19	0.30	0.04[2]	0.035	0.36	17.5	7.7	
8	99	0.46	0.60	0.03	0.029				

Aluminum Base Alloys

No.	Al[1]	Cu	Fe	Si	Mn	Mg	Ni
1	93.5	4.36	0.34	0.84	0.83		
1a	Alcoa 25S Propeller Forging Similar to No. 1						
2	94	4.01	0.46	0.23	0.73	0.57	
3	93.5	3.90	0.32	1.23	0.39	0.58	
4	90.5	7.98	0.59	0.98			
5	92.5	4.02	0.56	0.26		1.61	1.94
6	93	3.99	0.23	2.83			
7	95	0.02	0.29	4.71			
8	92	7.76	0.18	0.10			
9	95.5	0.02	0.15	0.12	0.5	3.66	

Magnesium Base Alloys

No.	Mg[1]	Fe	Mn	Al	Si	Zn	Cd	Cu
10	92		0.20	6.5		0.8		
11	92	0.03	0.39	6.35	0.06	0.75	0.02	0.04
12	90		0.24	8.86	0.40	0.51		

[1] By difference, approximate
[2] Less than

TABLE II. MECHANICAL PROPERTIES

Iron Base Alloys

No.	Form	Size, In.	Final Treatment	Tensile Strength lbs./in.²	Yield[1,9] Strength lbs./in.²	Elongation 1=4d %	Red. Area %	Impact Izod[2,10] ft.-lbs.		Fatigue Rotating Beam, lbs./in.²	Brinell 3000 kg.	Temperature of Test
1	Bar, rd.	⅝	Qoil 1625°F. Dair 1100°F.	128,000	122,000	20	65	81		69,000	285	Room
1	Bar, rd.	⅝	Qoil 1625°F. Dair 1100°F.	149,000	130,000	19	64	80		73,000	296	–40°C.
1	Bar, rd.	⅝	Qoil 1625°F. Dair 650°F.	219,000	196,000	13	57	13		96,000	429	Room
1	Bar, rd.	⅝	Qoil 1625°F. Dair 650°F.	228,000	200,000	13	55	14		100,000	432	–40°C.
2	Bar, rd.	¾	Cold Drawn	89,000	68,000	16	51	23	23[3]	——	179-175[3]	Room
2	Bar, rd.	¾	Cold Drawn	102,000	77,000	16	52	4	5[3]	——	192-183[3]	–40°C.
3	Wire, rd.	½	Cold Drawn	128,000	94,000	32	58	—	—	74,000	312	Room
3	Wire, rd.	½	Cold Drawn	144,500	——	34	57	—	—	77,000	337	–40°C.
4	Wire, rd.	½	Mill Annealed	98,000	——	60	72	—	—	41,000	175	Room
4	Wire, rd.	½	Mill Annealed	147,500	——	55	68	—	—	54,000	211	–40°C.
5	Wire	0.193[4]	Cold Rolled	242,000	160,000	6.5	51	—	16[5]	119,000	434	Room
5	Wire	0.193[4]	Cold Rolled	275,000	——	8	51	—	20[5]	——	434	–40°C.
6	Bar, rd.	1⅛	Mill Annealed[6]	108,000	41,000	48	—	No Fracture	99[7]	——	133	Room
6	Bar, rd.	1⅛	Mill Annealed[6]	158,000	37,000	41	—	118	94.5[7]	——	165	–40°C.
7	Bar, sq.	½	Cold Drawn	144,800	64,000	38	52	43		——	307	Room
7	Bar, sq.	½	Cold Drawn	198,400	60,000	33	35	19		——	323	–40°C.
7	Bar, sq.	½	Mill Annealed[6]	123,000	42,500	51	42	81	81[7]	——	205-181	Room
7	Bar, sq.	½	Mill Annealed[6]	182,000	50,000	34	30	32	66[7]	——	225-214	–40°C.
8	Wire	0.156[4]	Cold Rolled	175,000	129,000	7				——	288	Room
8	Wire	0.156[4]	Cold Rolled	184,000	139,000	7				——	306	–40°C.

Aluminum Base Alloys

1	Forging	2.5 to 1[8]	55,500	30,000	16	22	13	13,000[11]	102	Room
1	Forging	2.5 to 1[8]	58,500	31,500	13	20	13	16,000[11]	105	–40°C.
1a	Forging	3	60,600	37,400	21	27			112	Room
1a	Forging	3	66,000	39,800	17.5	31			112	–40°C.
2	Rod	9/16	58,000	42,000	23	42.5			112	Room
2	Rod	9/16	60,500	44,500	23.5	42			—	–40°C.
3	Rod	9/16	67,000	59,000	14	31			139	Room
3	Rod	9/16	69,000	58,000	13	31.5			—	–40°C.
4	Casting	½	24,500		2.2			7,000[12]	82	Room
4	Casting	½	26,600		1.7			9,000[12]	89	–40°C.
5	Casting	½ H.T.	39,500		1.0			7,000[12]	121	Room
5	Casting	½ H.T.	39,500		1.0			8,000[12]	115	–40°C.
6	Casting	½	21,300		2.5			7,000[13]	64	Room
6	Casting	½	23,300		3.0			7,000[13]	66	–40°C.
7	Casting	½	18,700		11.0			6,000[13]	45	Room
7	Casting	½	18,400		8.5			7,000[13]	44	–40°C.
8	Casting	½	21,700		3			7,000[12]	65	Room
8	Casting	½	21,700		3			8,000[12]	72	–40°C.
9	Casting	½	25,100		12.5			6,000[13]	58	Room
9	Casting	½	24,300		8.0			7,000[12]	59	–40°C.

Magnesium Base Alloys

10	Forging	2.5 to 1[8]	43,000	29,000	8.5	10	5.5	15,000[14]	63	Room
10	Forging	2.5 to 1[8]	39,000				4.7	16,000[14]	63	–40°C.
11	Forging	3.5 by 4	46,000	26,000	12	17.5		15,000[14]		Room
11	Forging							18,000[14]		–40°C.
12	Forging	2.5 to 1[8]	48,000	38,000	8.5	12	3		74	Room
12	Forging	2.5 to 1	58,000	40,000	7	7	2		78	–40°C.

[1] Set of 0.001 inch/inch from stress-strain diagram (A.S.T.M. Tentative Standards, Vol. 31, page 603).
[2] 0.394 by 0.394 inch with 45° V notch 0.079 inch deep with 0.010 inch radius at bottom.
[3] Heated to 1000°F. and cooled in air.
[4] Minor axis of the elliptical section.
[5] 0.226 × 0.345 inch with 45° V notch 0.050 inch deep, 0.010 inch radius.
[6] Impact and Brinell tests on specimens re-annealed by heating to 1950°F. and quenching in cold water.
[7] 0.394 × 0.394 inch with 45° V notch 0.120 inch deep, 0.010 inch radius at bottom.
[8] Thickness of Tapered Section.
[9] Set 0.002 inch/inch from stress-strain diagram in case of aluminum and magnesium base alloys.
[10] Aluminum Alloy See Note 2. Magnesium alloy 0.5 × 0.5 with V notch 0.079 inch deep and 0.010 inch radius at bottom.
[11] Fatigue Limit at 500,000,000 cycles.
[12] Fatigue Limit at 100,000,000 cycles.
[13] Fatigue Limit at 200,000,000 cycles.
[14] Fatigue Limit at 300,000,000 cycles.

proximately in the middle of the blade. The cast specimens were poured in green sand, using the Air Corps' standard test bar pattern and a pouring temperature of from 1250° to 1300°F. All bars were cast to size and tested without removing the skin. The No. 5 alloy was heated to 940° F. for 16 hours, quenched in cold water and aged at 375°F. for 5 hours.

The data for most of the stress-strain curves were obtained with an Olsen extensometer reading direct to 0.00005 inch/inch and estimating to 1/10. A few were made using the Ewing extensometer. The data were plotted to a scale of one inch equals 1000 lbs./in.^{2} and 0.0005 inch/inch in order to obtain greater accuracy for the modulus values.

Izod impact tests were made on notched specimens. The dimensions of the specimens are given in the footnotes to the tables as it was necessary to adapt them to the dimensions and characteristics of the stock. These values are of principal interest in indicating the effect of temperature change. The fatigue test specimens were the standard R. R. Moore type with a radius of 9 7/8 inches at the middle and a diameter of 0.330 for nonferrous alloys and 0.250 for the ferrous metals, except the streamline wires which had a smaller diameter and the notched specimens, Fig. 9. The fatigue specimens for the cast alloys were machined from 3/4 bars cast in green sand in a manner similar to the tension specimens.

The results obtained on the iron base alloys are comparable with those reported by other investigators.[2] The published data on tensile properties and hardness are not extensive but the results given for chrome-molybdenum and corrosion resistant steels in Table II are in

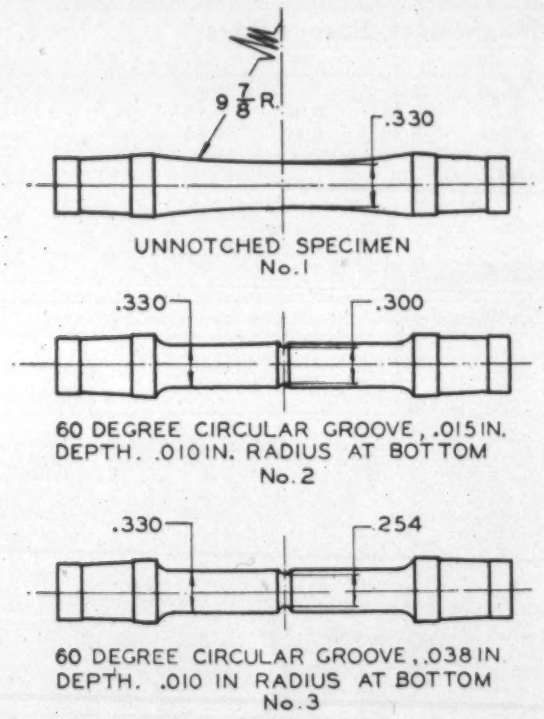


Fig. 5. Unnotched and notched Fatigue Specimens for Rotating Beam Machine.

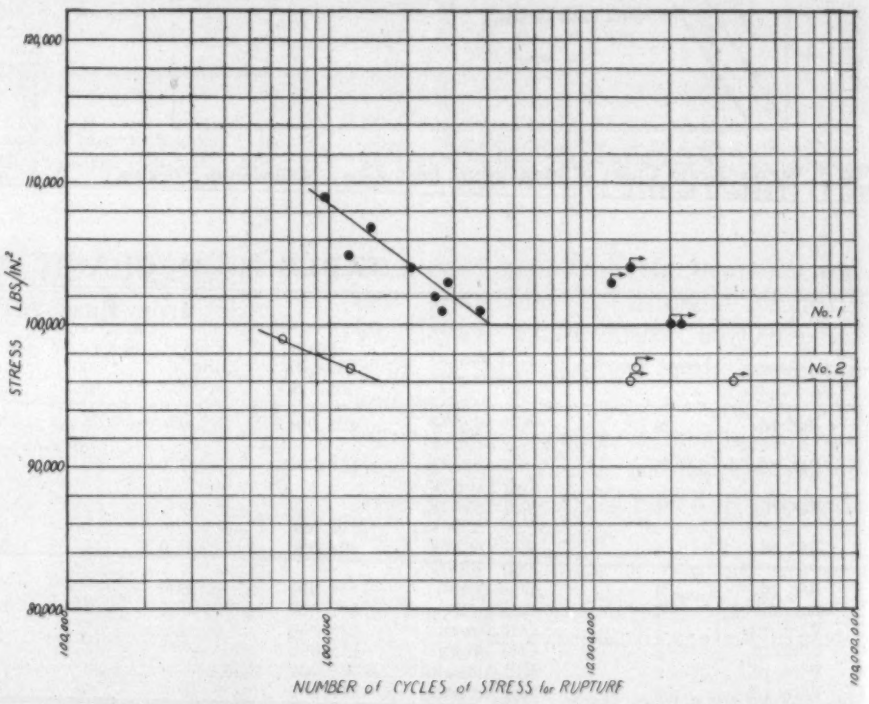


Fig. 6. Fatigue Chart of Iron base alloy. Chrome-Molybdenum Steel No. 1 (Tables I to III). Quenched in oil, drawn at 650°F. Curve No. 1 at −40°C. Curve No. 2 at Room Temperature.

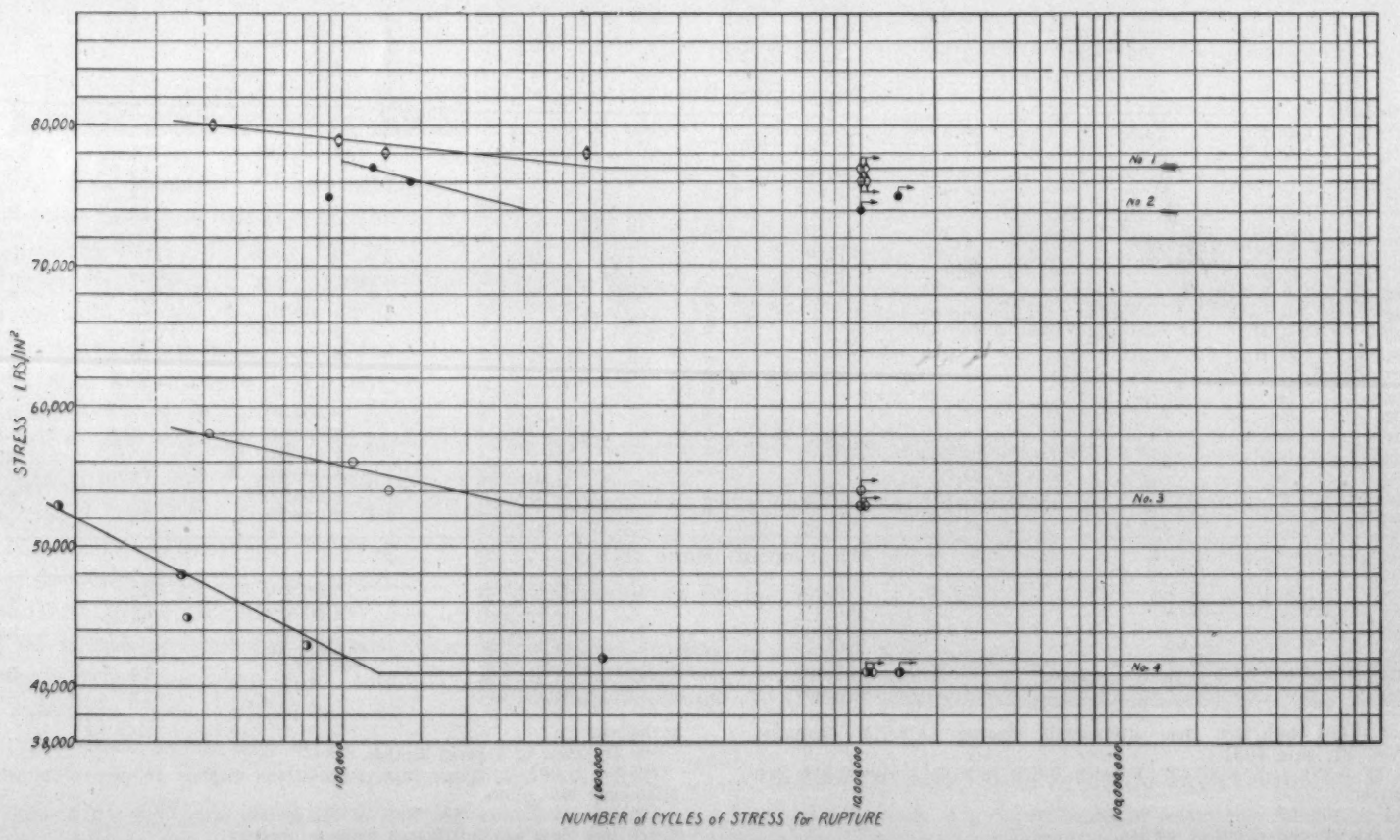


Fig. 7. Fatigue Chart of Iron base alloy. Chrome-Nickel Steel (18:8). Curve No. 1 at −40°C. Steel No. 3 (Tables I to III). Curve No. 2 at Room Temperature. Steel No. 3 (Tables I to III). Curve No. 3 at −40°C. Steel No. 4, annealed (Tables I to III). Curve No. 4 at Room Temperature. Steel No. 4, annealed (Tables I to III).

close agreement with those obtained on similar steels at the Battelle Memorial Institute.[3] The increase in tensile strength is quite marked, approaching 50% in the annealed corrosion resistant steel. The loss in ductility as indicated by the elongation and reduction of area is not appreciable.

It has been demonstrated by several investigators[2] that the notched bar impact test is the most sensitive indicator of the effect of sub-normal temperatures. Most steels show a rapid decrease in the notched bar value between + 20° and — 20°C., although a few steels appear to be exceptions to this, including the chrom-molybdenum and low carbon, chrome-nickel corrosion resistant steels. In the case of the medium carbon corrosion resistant steel, Tables I and II, the notched bar impact shows a decrease which is accentuated by cold work. The specimens for steel Nos. 6 and 7, reported in the right-hand side of the impact column in Table II were annealed in a laboratory furnace. The impact value for cold worked carbon steels is much lower at −40° than at room temperature, whereas, the low carbon corrosion resistant steel cold drawn and rolled to an elliptical section, No. 5, Table II, is unaffected.

The data on the properties of aluminum and magnesium alloys at sub-normal temperatures are very limited. Templin and Paul[4] published data comparing the tensile properties of several alloys at + 20° and −80°C. Their tests show an increase in ultimate and yield strengths and elongation for the aluminum alloys at the latter temperature. Bollenrath[5] investigated the elastic properties of a series of aluminum and magnesium alloys over a wide range of temperature. In general there was an increase in modulus of elasticity and elastic limit (0.01% extension) except for the aluminum alloys with an appreciable content of silicon which developed a maximum between 0° and −40°C.

The data given in Table II agree with these results, although the ductility as measured by elongation and reduction of area is practically unaffected by the change from room temperature to −40°C. There is an increase in tensile strength but in the case of the

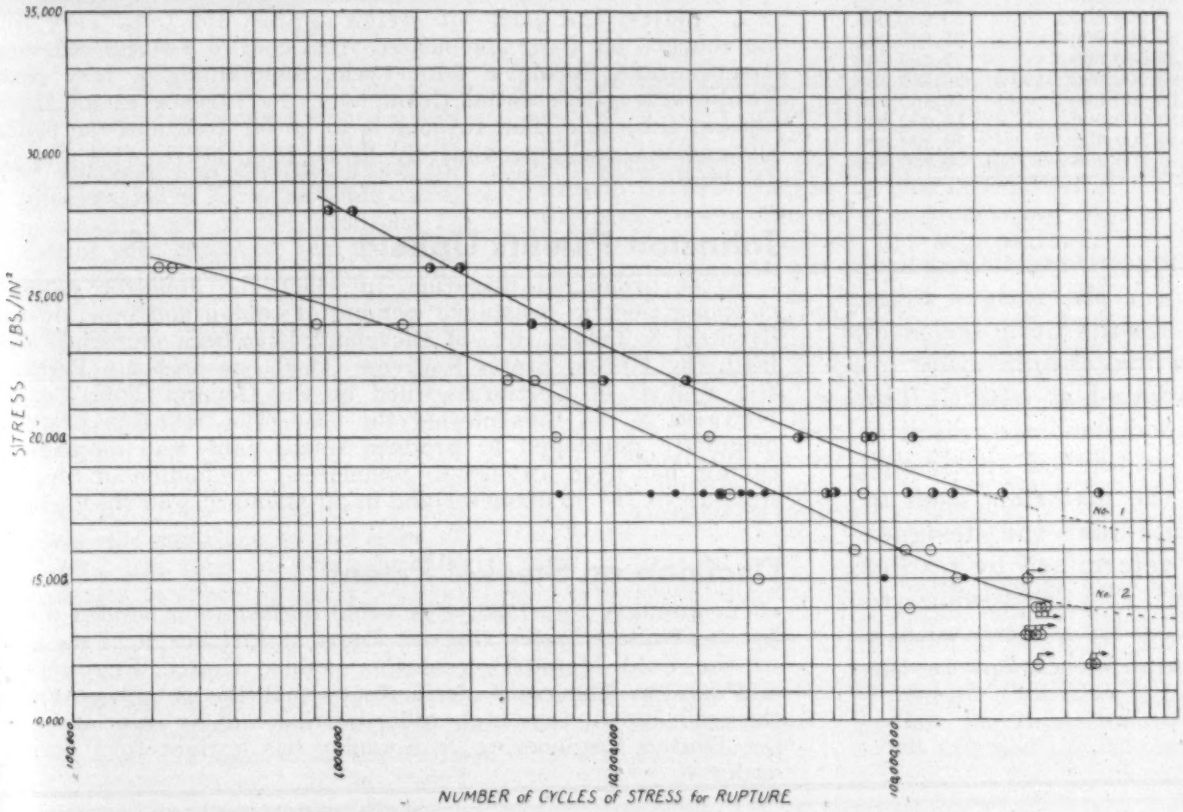


Fig. 8. Fatigue Chart of Aluminum base alloy. Forging No. 1 (Tables I to III). Curve No. 1 at −40°C. Curve No. 2 at Room Temperature. Open circles and solid circles represent specimens tested at room temperatures, but taken from two different forgings, the half shaded circles represent test at −40°C. and specimens from same forging as represented by solid circles.

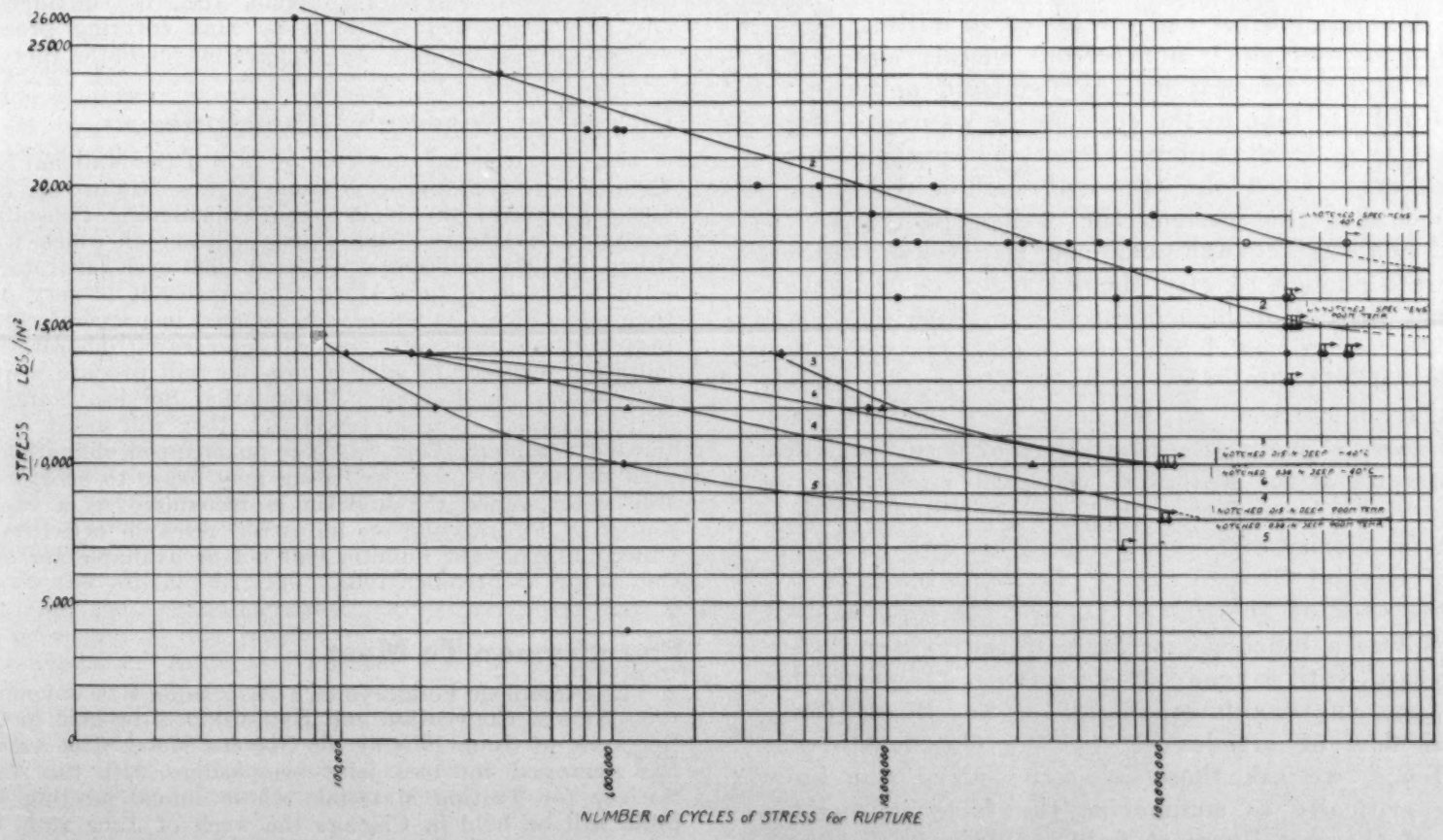


Fig. 9. Fatigue Chart of Magnesium base alloy. Notched and unnotched specimens. Magnesium forging, No. 11 (Tables I to III).

cast alloys this increase is too small to have any significance. Fatigue limits are slightly higher at the low temperatures. The energy absorbed by a notched bar specimen is slightly less at −40°C. for the magnesium alloys.

The values for modulus of elasticity in Table III were obtained on the identical alloys listed in Table II and are referred to by number. Corrosion resistant steel is the only material which shows a difference between the values at the 2 temperatures which is outside the limits of experimental error and variability of sample.

Table III. Modulus of Elasticity (lbs./in.²) in Tension.

No.	Material	Room	−40° C.
1	Steel, Chrome-Molybdenum(1)	30,000,000	30,500,000
1	Steel, Chrome-Molybdenum(2)	30,000,000	30,000,000
6	Steel, Chrome-Nickel	29,000,000	37,000,000
7	Steel, Chrome-Nickel, annealed	30,000,000	37,500,000
7	Steel, Chrome-Nickel, Cold rolled	28,000,000	36,500,000
1a	Aluminum Alloy (25S)	10,400,000	10,800,000
2	Aluminum Alloy (17ST)	10,000,000	10,000,000
3	Aluminum Alloy (S17ST)	10,300,000	10,300,000
12	Magnesium	6,400,000	6,300,000

(1)Drawn at 650° F.
(2)Drawn at 1100° F.

The effect of a notch on the fatigue properties at normal temperatures is always to lower the fatigue limit. It is interesting to note that the results of a series of tests on an aluminum alloy and a magnesium alloy indicate that the effect is not accentuated at −40°C. The fatigue properties of the notched specimens are raised in about the same proportion as the unnotched specimens.

The results of all the tests on the materials used in aircraft construction would indicate that the designer is safe in using allowable stresses determined by testing material at normal temperature. The resistance to fatigue, or a suddenly applied load on a part with a sharp change of section, is not impaired except in the case of the cold rolled carbon steel.

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Editorial Comment

(Continued from Page A 9)

The Mining and Metallurgical Engineers' Meeting

IT'S A tough job for one interested in milling, smelting, iron and steel, non-ferrous metals and a few other things covered by the manifold activities of the A.I.M.E. to take in the sessions he wants to attend, unless he is at least triplets. Hence, no single observer can correctly report the trend of such a meeting. It happened that the sessions the writer picked out to attend had a small enough number of papers, and authors considerate enough to give them briefly, so that there was time for old fashioned discussion. And there was useful discussion, which indicates that it is not a lost art as one would think from so many of the breathlessly crowded technical sessions that have been inflicted upon the audiences at many other meetings of many societies.

We weren't at the session at which he spoke, but we are credibly informed that Wheeler P. Davey rates a bouquet for clarity of presentation of his talk on Mechanism of Crystal Growth and its Consequences.

For the staff of METALS & ALLOYS, the high spot of the week was a luncheon meeting of the Editorial Advisory Board, with a very full attendance. Of particular interest was the unanimous desire of the Board for a continual flow of articles of the Correlated Abstract type. Hence, we ask those of our readers who have occasion critically to summarize the facts in various corners of the metallurgical field, to submit the summaries for publication.—H. W. GILLETT.

Alloy 548

Alloy 548, a new alloy with a field of application between high speed steels and cemented carbides, was announced at a recent Cleveland meeting of the American Society for Steel Treating by Dr. Jeffries, President of Carboloy Company, Inc. The company states that this announcement was intended as a general statement of the present status of development and application from the standpoint of metallurgical interest, rather than as a formal, commercial release.

Rust Receives Contract

The Rust Furnace Co. was awarded, by the Babcock & Wilcox Co., the contract for designing and building the Hoover Dam stress relieving furnace which will be used to heat sections of welded steel pipe to relieve welding stresses. These pipe sections will be 30 ft. diameter by 24 ft. long, made of 2⅞" plates, and each will weigh approx. 150 tons. They will be charged on a car and heated from cold to a stress relieving temperature during a 6-hr. cycle, maintaining a very close temperature differential throughout the furnace at all times during the cycle. The furnace is to be oil fired and the inside dimensions are approximately 41 ft. long, 36 ft. wide and 30 ft. high.

Johnston Patents Upheld

After prolonged litigation, in which the Johnston patents covering electric resistance welding of tubing and pipe, owned by Steel & Tubes, Inc., of Cleveland, have been uniformly upheld, the United States Supreme Court has denied a Petition for a Writ of Certiorari, filed by the General Tube Co. of Newark, N. J., thus closing the case. The Johnston process, originally developed to produce small, light wall mechanical tubing, has been applied to commercial production of pipe in sizes up to 16" in diameter and in all standard wall thicknesses.

Decision on Steckel Patent

On January 9th, 1933, a two-fold decision was handed down by the United States District Court at Pittsburgh in the suit of the Cold Metal Process Co. against United Engineering & Foundry. The court decided (1) that the patent, covering the well known four-high roller-bearing mill, is valid and (2) the United Engineering & Foundry has a right to a license under it.

Chromium Plating Patent Upheld

On January 23rd, 1933, the Supreme Court of the United States denied a Petition for a Writ of Certiorari filed by the International Silver Company, defendants in a suit brought against it by United Chromium, Inc., for infringement of the patent granted to Colin D. Fink covering processes of chromium plating and the preparation of baths therefor.

Industrial Research Laboratories

The Research Information Service of the National Research Council is preparing a revision of its "Industrial Research Laboratories of the United States, including Consulting Research Laboratories," the fourth edition of which was published in 1931 and contained over 1600 such laboratories.

In addition to these 1600 laboratories it is very desirable that any which may have been omitted in previous editions be listed. If members of firms whose research laboratories have not been included in earlier bulletins will procure a questionnaire from the Research Information Service, National Research Council, Washington, D. C., they will assist in making the list complete. This calls for no financial obligation on the part of any firm and the listing may prove to be of considerable value, since the bulletin is recognized as a convenient source of information on industrial research activities in the United States. The bulletin will not be available for distribution before September 1933.

Foundrymen To Meet

The American Foundrymen's Association has announced its 1933 Annual Convention and Exposition to be held in Chicago the week of June 19th at the Stevens Hotel. The Association has arranged for two joint symposiums with the American Society for Testing Materials whose annual meeting and exhibit will be held in Chicago the week of June 26th. One of these will be on Methods of Testing Castings and the other on Gray Cast Iron.

Robert F. Mehl

ETCH PITS in IRON
Their Use in Determining the Orientation of Iron Crystals

Dana W. Smith

By DANA W. SMITH* and ROBERT F. MEHL*

The inadequacy in the use of etch pit traces for the determination of the orientation of crystals is pointed out, and a complete method for a unique determination of orientation is described. This method makes use of the directions of etch pit traces and of the approximate positions of etch pit planes. An etching technique, using an aqueous solution of copper-ammonium chloride, which has been shown satisfactory for the purpose, is described. This technique develops dodecahedral and only dodecahedral pits in iron. The method described will determine the orientation of an iron crystal within about 3° of the orientation determined by X-rays.

SEVERAL methods are now available for the determination of the orientation of crystals. These include a number of X-ray methods, methods making use of the positions in space of slip, cleavage, and twinning planes, and methods employing etching with the development of etch pits bounded by known crystallographic planes.

Etch pits may be used for this purpose in two different ways. In the first, the angles in space of specular reflection from the sides of the etch pits are determined with a reflection goniometer. These angles serve to determine the positions of the sides of the pits and thus to determine the orientation in space of the crystallographic planes defining the etch pit, from which the orientation of the crystal may be derived.[1] A preliminary determination of the type of crystallographic plane developed is always desirable.

In the second, individual etch pits are studied for the purpose of determining the directions taken by the intersections of the etch pit sides with the surface of polish (hereinafter known as the "traces"). In this case the type of crystallographic plane developed must always first be determined. This method may sometimes be applied where no other is suitable, particularly in the determination of the orientation of very small crystals. The application of this method is by no means simple, as we shall show; much of the work in the literature is open to criticism because of inadequate analysis of the problem. The purpose of this communication is to describe a proper application of this method with necessary extensions, with examples for which the requisite data have been procured.

Relatively few reliable determinations of the crystallographic planes developed in the etching of iron are available.[2] Andrews[3] reported that 2% nitric acid in water develops cubic etch pits in iron, judging from simple inspection. Stead[4] studied pits developed in iron and also in 4% silicon steel by means of dilute nitric acid, and from their shape concluded that the etching agent developed the cube planes. Although we now know these conclusions to be correct, we shall see that simple inspection of shape may be entirely misleading.

Using a simple optical method for studying specular reflection, Tammann[5] found aqueous solutions of ammonium persulphate to develop cube planes in iron, occasionally associated with dodecahedral. McKeehan,[1] combining an X-ray determination of orientation with goniometric measurement of positions of specular reflection, demonstrated that dilute nitric acid develops cube and only cube planes in iron.

With proper care aqueous solutions of copper-ammonium chloride will develop sharply defined pits in iron. Svetchnikoff[6] developed pits with this reagent and concluded from their appearance that cube planes, occasionally combined with octahedral and dodecahedral planes, had been developed.

The determination of a crystallographic plane defining an etch pit, and the use of known etch pits for the determination of crystal orientation may best be shown by the use of the stereographic projection. The etching technique described here produced dodecahedral, {110} planes in iron. The generalizations about to follow apply chiefly to the development of {110} planes, but may be applied in detail to other planes upon suitable transformation.

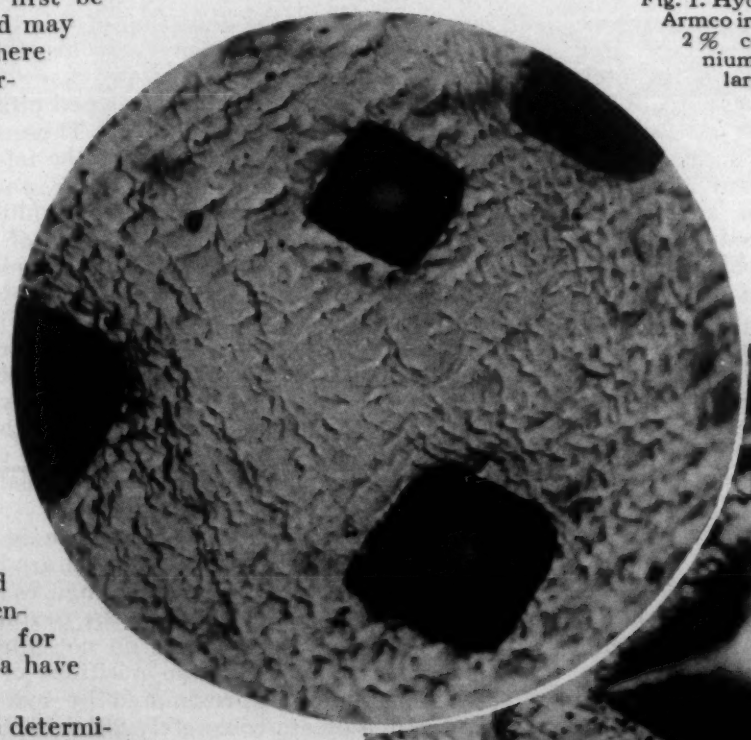


Fig. 1. Hydrogen purified Armco iron etched with 2% copper - ammonium chloride. Pits large and deep. Magnification 1000X.

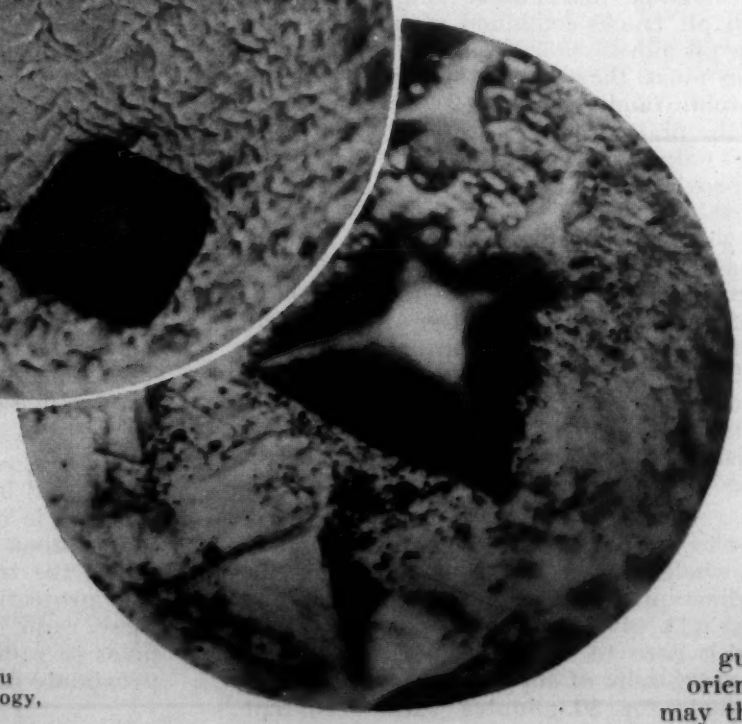
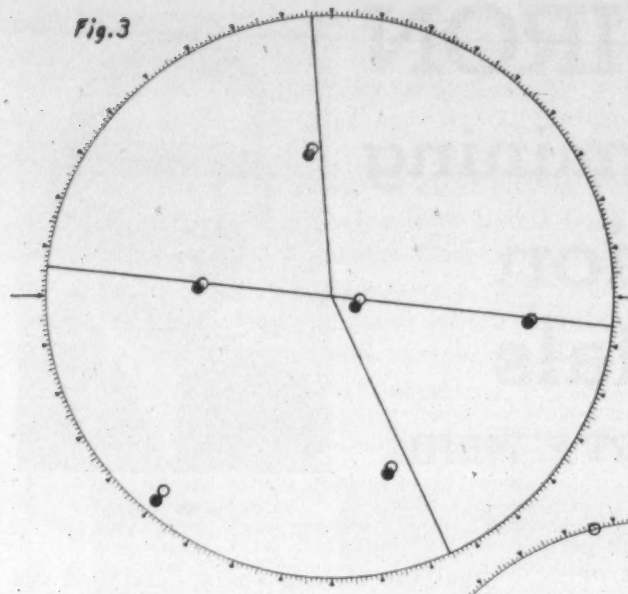
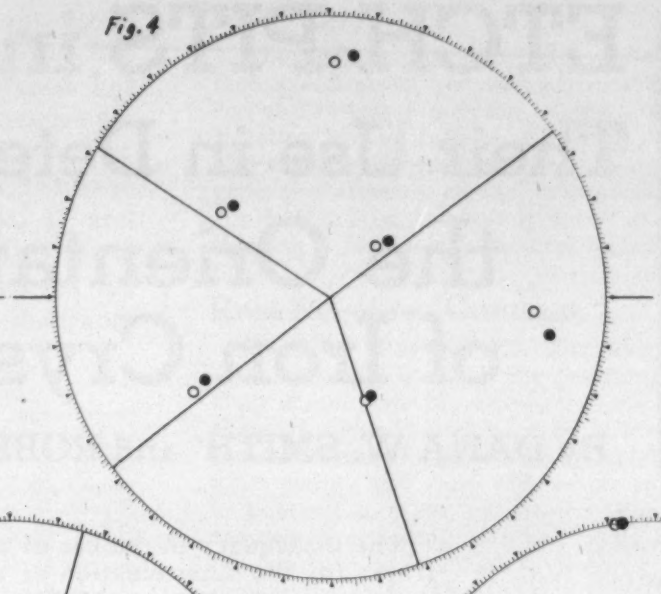


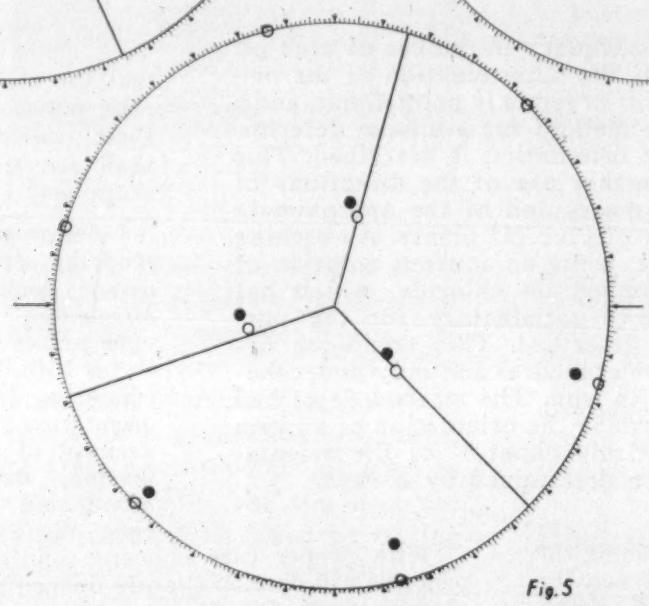
Fig. 2. Same grain as in Fig. 1 electrolytically etched in 0.5% copper-ammonium chloride. Pit is shallow. Magnification 1500X.

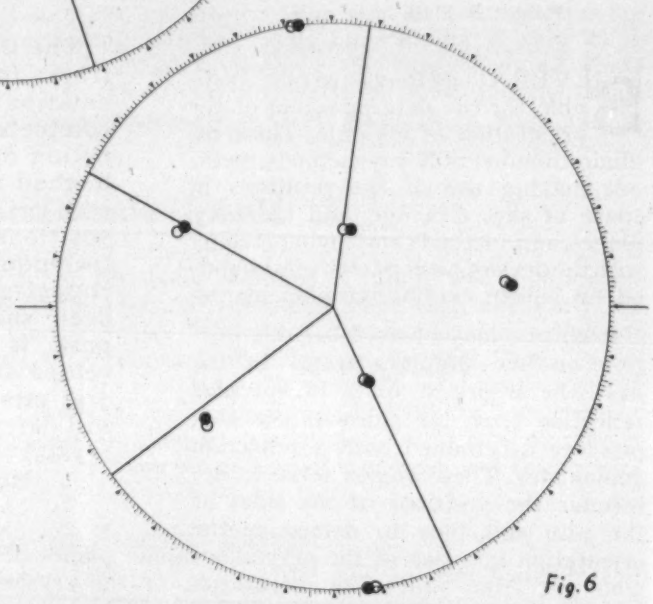
It may be shown stereographically by rotation of poles of planes that: (1) in the general case, the development of the maximum possible number of traces from any crystallographic plane will not uniquely determine the orientation, but will give a choice of two possible orientations; (2) within a spread of a few degrees, which easily includes experimental error, in certain orientations, five of the six possible dodecahedral traces will not distinguish among four possible orientations. In general it may therefore be said that an

*Assistant Metallurgist and Director, respectively, Bureau of Metallurgical Research, Carnegie Institute of Technology, Pittsburgh, Pa.









Figs. 3, 4, 5 and 6. Stereographic Projections. Radii represent normals to traces of etch pits. Open circles are {110} poles rotated from a standard projection into as close a match as possible with the radii. Large dots are {110} poles independently located from X-ray data.

analysis of trace directions *alone* is not sufficient to establish an orientation.

An orientation may be uniquely established, however, by determining the approximate directions in space of the normals to etch pit planes. For this purpose it is necessary to confine attention to well developed pits whose sides are definitely continuous from the bottom of the pit to the surface and whose sides are not reëntrant; i.e., do not undercut the surface. For such pits the slopes of the sides—the angle between the etch pit sides and the surface—can be estimated by eye to about $\pm 10°$.

With the etching technique here described no dodecahedral planes were developed which lay within a range of 20° from either parallelism or perpendicularity with the surface of polish, therefore the slopes were always estimated to lie between 20° and 70°. A systematic study of the problem using a model and a stereographic net failed to disclose any crystal orientation which could not be determined uniquely from a measurement of the etch pit traces combined with an estimate of the slopes of the etch pit sides.

The etching technique must therefore: (1) develop planes of only one crystallographic family, {hkl}, (2) develop traces which lie accurately in the planes {hkl}, (3) develop no reëntrant etch pit planes, (4) develop the bottom of the pit well enough to permit an approximation of the slope of the sides of the pit.

Electrolytic etching with an aqueous solution of copper-ammonium chloride was used. It was found that the above conditions are best met by the development of very small, shallow pits. Large, deep pits developed by the same reagent are deceptive. Fig. 1 shows a large, deep pit, and Fig. 2 a small, shallow one on the same crystal. The crystal in each photomicrograph bears the same relative position with respect to the printed page. It may be seen that the traces are widely different in angular position. We may note further that the pit in Fig. 1 suggests cube etching though the true etching is dodecahedral.

Electrolytic etching is to be preferred over simple etching because it activates the whole surface and thus facilitates the formation of small, shallow pits. The details of the etching technique are as follows: (1) give the specimen a very good metallographic polish with care to avoid deep-seated distortion, (2) electrolyze in a 0.5% soln. of copper-ammonium chloride with specimen as anode for 30 minutes with a current density of 0.005 amp./cm.^{2}, (3) wash, (4) polish lightly with magnesia, (5) re-electrolyze as above, (6) wash and dry. This etching technique was found satisfactory for the study of the orientation of grains of hydrogen-purified carbonyl iron, of hydrogen-purified ingot iron, and of pro-eutectoid ferrite in slowly cooled hypoeutectoid steels. Variation in composition may well require modification of this technique, but the criteria for proper etching in any case are those outlined in the preceding paragraph but one.

This technique usually developed pits, but occasionally pyramids in relief were observed.[7] These could readily be recognized by changing the focus of the microscope and by the use of illumination at a grazing angle, and were as useful in the analysis as pits. In the use of pyramids it is necessary only to take care in the plotting the poles of the pyramid faces.

As stated above the etching technique described develops dodecahedral, {110}, planes in iron. This is shown by the stereographic plots Figs. 3-6. Upon each of these plots is represented: (a) the directions of normals to etch pit traces as radii, (b) the poles of the {110} planes rotated from a standard projection into the best fit as judged by coincidence with radii and with the estimated location of the {110} poles, as open circles, (c) the poles of the {110} planes, the positions of which were independently determined by X-rays, as heavy dots.

In each case the correspondence is close enough to prove that the etch pit planes developed are indeed the {110} planes. We may also see from these figures that {110} planes, the projections of which lie near the periphery or near the center of the stereographic circle, do not appear as etch pit planes. In each case pictured the positions of the projections of the etch pit planes approximated by eye corresponded within a total range of approximately 20° with the positions determined by X-rays.

The use of etch pits for solving an unknown orientation is illustrated in the examples of Figs. 3-6. A stereographic projection[8] is made with the surface of polish as the projection plane; upon the projection are plotted radii drawn perpendicular to the traces of the etch pit sides in the surface of polish. The projection of the poles of the etch pit sides will lie upon these radii. (The elimination of reëntrant sides confines the poles to radii instead of diameters on the projection.) The approximate number of degrees along a radius from the center of

(Continued on page 36)

EARLY CHEMISTRY and CHEMISTS in the IRON and STEEL INDUSTRIES — No. 3

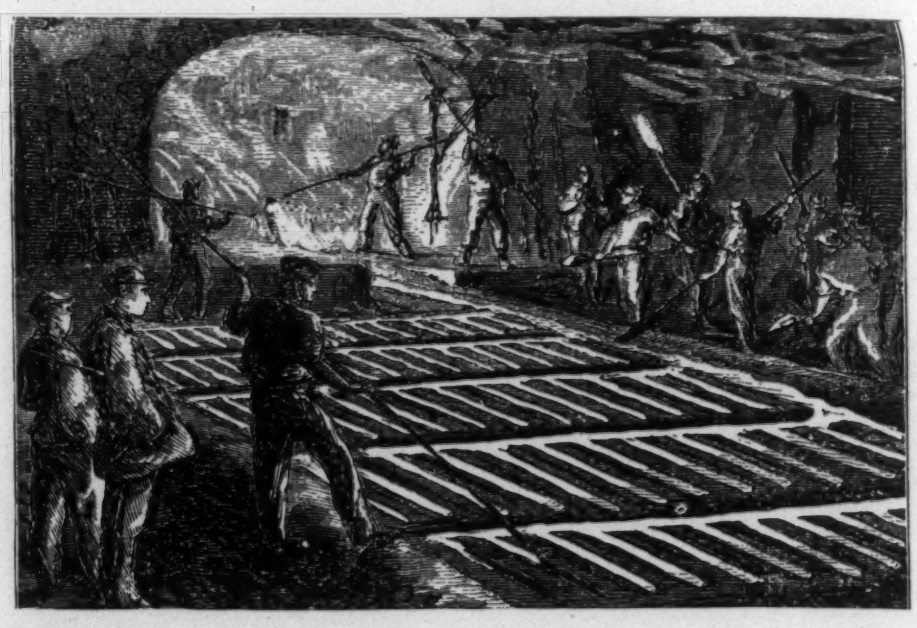
SCENES Around the Early Blast Furnaces

By L. W. SPRING and L. E. GILMORE

THOUGH the metallurgist would term the blast furnace masculine because he considers it the King of metallurgical devices, the furnace gang considers it almost a living thing and refers to it as "she." One early chemist states that he fully agreed with the workmen that the furnace indeed was a "she." "She had her moods, and often they were trying ones, although of course she was not always sick. We just loved her when she was well and performing beautifully."

Where else have we a thing of three genders—neuter, masculine and feminine?

The blast furnace is very important since it is the start of the whole iron and steel procession. Iron ore, coke and limestone in the blast furnace become, not mere dust, carbon and stone, but that useful metallic product pig iron, the raw material from which wrought iron, cast irons, malleable irons, and our multitude of soft and alloy steels are made, the sinews for the modern "Age of Steel." What would this civilization be without iron and steel bars, rods, wire, castings, rails, structural steels, etc. Think of our locomotives, ships, bridges, skyscrapers, dynamos, generators, steam shovels, telephone, telegraph, tractors, automobiles, etc.



The old way. Casting scene at an anthracite furnace in the sixties. From an old wood cut reproduced in "Two Centuries of Iron Smelting in Pennsylvania" by Richard Peters, Jr.

But in 1750 all was not so, nor in 1800, 1850 nor 1880. Many of us have witnessed the real "flowering" of this plant which has been so many years in developing. While the chemist does not appear in the blast furnace picture except during the past 50 years or so, the romance of the blast furnace in this country is well worth while, as a background for the chemist.

The fuel of the first furnaces was charcoal. In some regions anthracite coal was used, between the charcoal and coke eras. Now of course it is coke. Instead of our present day "hundred footers," the furnaces of a hundred years ago were small affairs partly because charcoal crushed easily under the great "burden" of ore and, further, because more powerful engines and mechanical equipment were lacking. Also the "hot blast" had not yet arrived.

"The operation of the primitive furnaces extended over a period of about 9 months each year, after which they were put out of blast, usually in the autumn, so that the workmen could be employed in cutting wood preparatory for the charcoal burning during the winter and early spring. It was the general practice to employ all the hands at the plant in the task of getting the fuel ready for the succeeding year's campaign. During the period of shutdown, a new hearth was put in place and this essential part of the furnace was generally hewn from solid sandstone, the work being entrusted to the care of the founder."

Peters' "Two Centuries of Iron Smelting in Pennsylvania" (1921) from which the above is quoted gives quite a complete picture of the blast furnace industry in the Keystone state. A main episode of the development of the anthracite furnace, so important to an anthracite region, is told in the coming to America of David Thomas, after whom the important Thomas Iron Co., was named.

Quoting his son, Samuel Thomas of Catasauqua, Pa. speaking at the A.I.-M.E. California meeting in 1899:

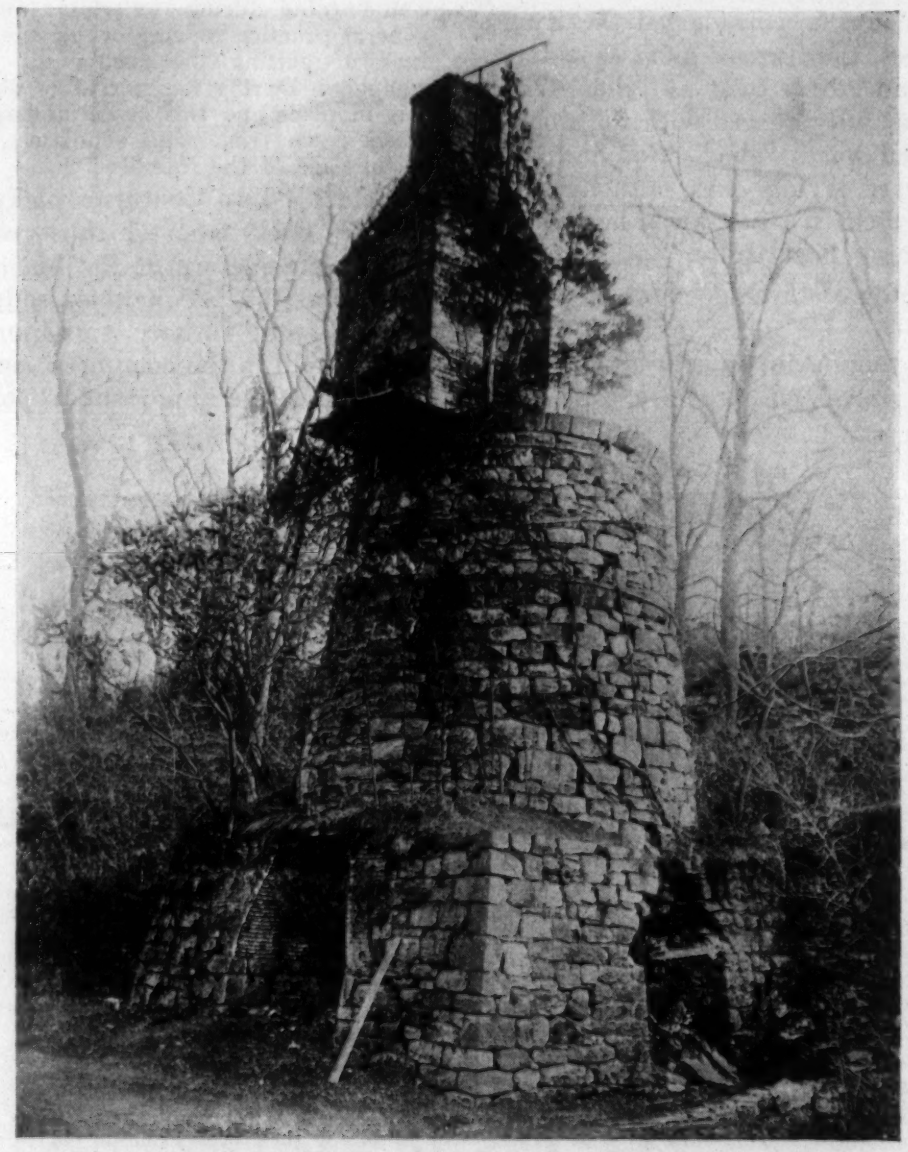
"David Thomas, my revered father, called by his Welsh countrymen 'the pioneer of the anthracite iron-trade in America,' was one of the principal actors in the history of manufacturing pig-iron with anthracite coal. I shall give here my personal recollections of his early experiments, trials, and final successes, as frequently related by him to me, together with quotations from a biographical sketch by E. Roberts, found in the number for October, 1883, of the 'Red Dragon', the national magazine of Wales. Mr. Roberts' narrative is authentic, by reason of his free access to the records of the Yniscedwin anthracite ironworks during his long connection with them.

"As early as 1820 Mr. Thomas began to experiment in Wales with anthracite coal in the blasting-furnace, using it with coke in the proportion of from 1 part in 20 to 1 part in 12. 'This did very well,' Mr. David Thomas used to say; 'but whenever anything went wrong with the furnaces the fault was always laid on the coal; and the men became so prejudiced against it that I had to give up. Still, every year I would try some experiments with it, both in cupola and blast-furnaces' . . . 'In 1825 I had a small furnace built, 28 feet high and 9 feet bosh, which was put in blast with coke and an increased amount of anthracite. Results were not satisfactory, and this furnace was abandoned. In 1830 the same furnace was made 45 feet high and 11 feet bosh; and, while the experiments were much more successful than previously, the consumption of coal who so great as to make results unprofitable, and the work was again abandoned.'

"About this time experiments were also being made in Pennsylvania, but with no better success than in Wales. While this was being done on both sides of the Atlantic, another brain was at work, which furnished the key that unlocked the secret to success, by Mr. Neilson, of Glasgow, the inventor of the hot-blast, who in 1828 obtained a patent for his valuable

invention, the importance of which was not realized for a long time. The pamphlet on the hot-blast, issued by Neilson, was eagerly read by Mr. Thomas, who was at once convinced of the value of the discovery. One evening, while sitting with Mr. Crane in his library, talking the matter over, he took the bellows and began to blow the anthracite fire in the grate. 'You had better not, David,' said Mr. Crane; 'you will blow it out.' and Thomas replied, 'if we only had Neilson's hot-blast here, the anthracite would burn like pine.' Mr. Crane said, 'David, that is the idea precisely,' and this idea both recognized as one which would bear working out; and through Mr. Thomas' indomitable pluck and perseverance it succeeded. In fact, this was the origin of the successful application of the hot-blast in making iron with anthracite.

"In May, 1837, Solomon W. Roberts, of Philadelphia, came to Yniscedwin, saw the furnace in operation, and at once reported to his uncle, Josiah White, of the Lehigh Coal and Navigation Company, the successful application of the hot-blast there. At this time, 1837-1838, the Lehigh Coal and Navigation Company, and other companies whose splendid mines cluster in the neighborhood of Mauch Chunk, Pa., were experimenting in the use of anthracite in blast-furnace, but with such small success that it was determined to send Mr. Erskine Hazard, one of the leading spirits of the company, and afterwards *the* leading spirit of the Lehigh Crane Iron Company, over to Wales, to investigate the practice at Yniscedwin and engage a competent person to come to this country to superintend the erection of furnaces on the Lehigh. Mr. Hazard arrived in November, 1838, and found the furnace in full and successful operation."



Ruins of Cordorous Hot Blast Charcoal Furnace near Manchester, York Co., Pa., originally built in 1836 and operated by E. & C. B. Grubb. Note circular stone work above boshes in place of usual truncated pyramid. From a photograph in the collection of Richard Peters, Jr.

Samuel Thomas continues:

"The first week of May, 1839, found our little family group at Swansea, on board of one of the coast-steamers on our way to Liverpool, as there were no railroads across the country at that time. The steamer 'Great Western' had made but two or three voyages across the Atlantic; so, after much discussion among the parties interested, it was decided that, as steam was still considered a dangerous venture, we should take a sailing-vessel; and our passage was engaged on the clipper-ship 'Roscius.' Our first month on American soil was spent in New Brighton, Staten Island, where my father lay very ill of a fever, and was faithfully attended by Dr. Harcourt, the genial quarantine physician. On his recovery, he took me with him to Philadelphia, where he had been called to attend a meeting of the Crane Co.'s Board, relative to his entering upon his duties. We returned to New Brighton July 4, and two days later turned our faces toward the Lehigh Valley, our future home,* taking the New Jersey Railroad via Jersey City and New Brunswick, at that time the terminus of the road, which, it may be of interest to note, was laid with strap-rails. From New Brunswick the journey was continued by stage, the first night being spent at Easton, and Allentown being reached July 9.

"About August 1, serveys and plans being completed, work was commenced on excavations for the foundations of the wheel-pit and on a branch canal, 25 feet wide, which was to be the feeder or race-way to the water-wheels, and also the route for boats to bring material to the works. The excavation was under the charge of Robert McIntyre and William Paul. A little later, the hot-blasts and furnace foundations were commenced; the furnace being some 30 feet square at the base, 12 feet bosh, and 45 feet high. All the masonry was laid by Isaac McHose, Sr., of Ritterville, whose son, Samuel, was subsequently the builder of nearly all the furnaces in the Lehigh Valley. The elevator for filling the furnace, called 'a water-balance,' consisted of two square boxes of sufficient size, one on each end of a chain, passing over a large wheel with a brake; a sufficient amount of water being admitted into the boxes on top to bring up a load on the other side, while the water escaped out of the boxes automatically at the bottom.

"About mid-summer of 1839, such portions of the outfit for this furnace as had been constructed on the other side of the Atlantic, were shipped (some castings being made here later on), except the two blowing-cylinders, which the hatches of the ship were too small to admit. The vessel was also laden with rails for the Lehigh Coal and Navigation Co. and cleared for Philadelphia; but, having sprung a leak, she put into Norfolk, Va., in distress, after having jettisoned about 300 tons of rails. On receipt of this news, Mr. Hazard and my father went to Norfolk, and, to their consternation, found the cylinders were not there; the captain telling them, in language more forcible than elegant, that if the castings in the hold had not been so heavy they would have gone overboard also. After necessary repairs, the vessel proceeded to Philadelphia; and thence all the material for the furnace was shipped by canal to the works. Steps were taken at once to procure cylinders. Application was made to Alger at Boston; the Allaire works, and the Morgan iron works of New York; but they all declined to undertake the work, as they could not bore cylinders of that size, and would not enlarge their mills for the purpose.

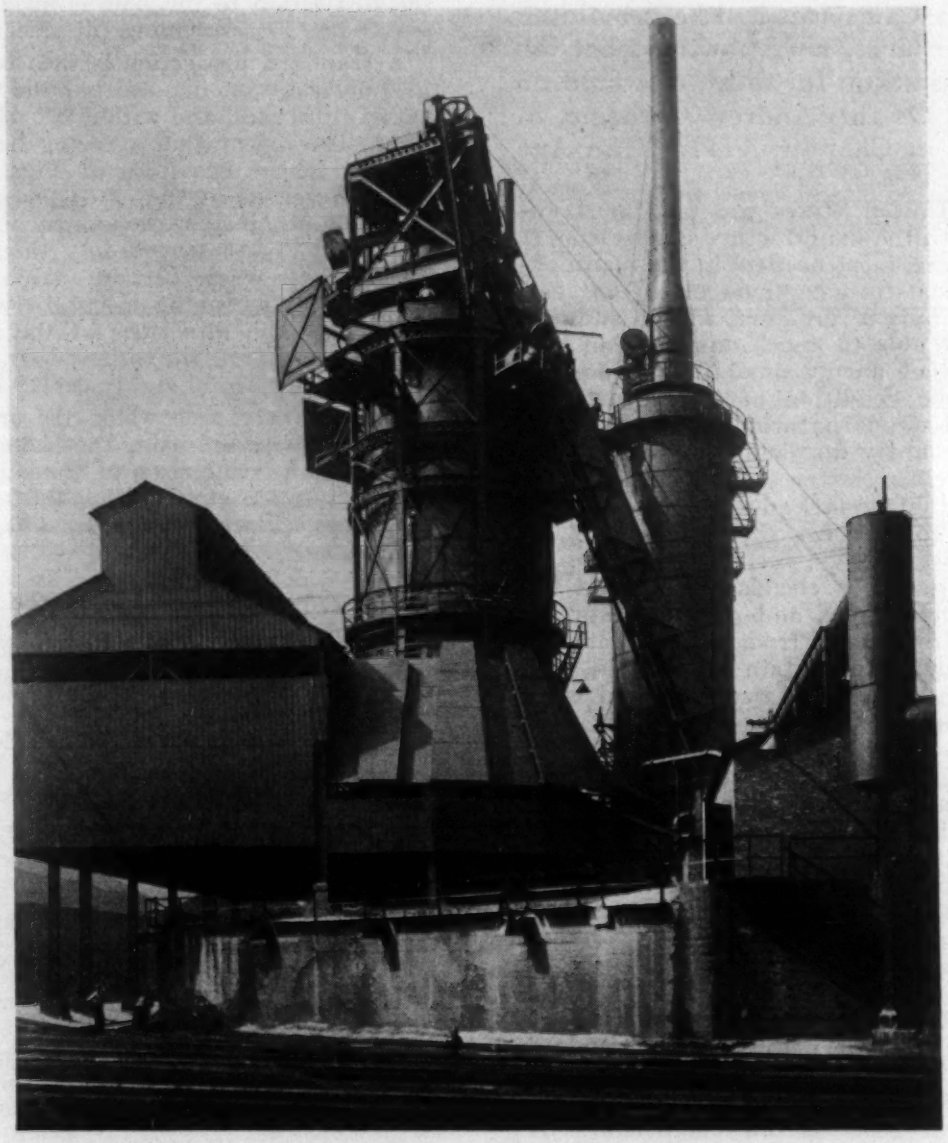
"At this time there was not a boring-mill in the United States large enough to bore a cylinder of 60 inches diameter; but American progress in the construction of machinery was so rapid that in 1851 the I. P. Morris Co. of Philadelphia, Pa., made four cylinders for Ericsson's hot-air ship, of 168 inches diameter and 6 feet stroke. Application was then made to Merrick & Towne, of the Southwark foundry, Philadelphia, who agreed to undertake the work, enlarging their boring-mill for the purpose, and succeeded in making two very fair cylinders, for which 12½ cents per pound was paid. These

*Catasauqua, Pa.

cylinders were bored by Harry Smith who fitted them to the tops and bottoms sent from England, and subsequently erected them in place. The original cylinders, which had been so unceremoniously left on the docks at Cardiff, finally arrived at their destination in 1840. They were unloaded at lock 36, and one of them figured in the great flood of 1841, being rolled by the water a quarter of a mile down to Biery's bridge, where it lodged in a deep gully. Later, these cylinders were used in the construction of two blowing-engines, which were erected back of No. 1 furnace.

"After many vexatious delays, the furnace was completed and successfully blown in at 5 o'clock P. M. July 3, 1840, and the first cast of about 4 tons of iron was made on the memorable 4th of July of that year, the keepers in charge of the furnace being William Phillips and Evan Jones. The furnace remained in blast until its fires were quenched by the rising waters of the great flood of January, 1841, a period of six months, during which 1080 tons of pig iron were produced. The largest output for one week was 52 tons.

"Furnace No. 1 was blown in again after the freshet, May 18, 1841, and then remained in blast until August 6, 1842, producing 3,316 tons of pig-iron. My father had been very generally looked upon as visionary. The remark made by a leading charcoal iron-master, whom I well knew, 'I will eat all the iron you make with anthracite,' gave expression to the general sentiment of the trade at that time. It is needless to say that he did not keep his promise, although my father cordially invited him to a hearty dinner, cooked in the company's first furnace.



A Modern Iron Maker of the Pittsburgh District. (Courtesy Carnegie Steel Company.)

"After the success of this furnace had been fully established, anthracite furnaces began to multiply rapidly; Post built at Stanhope, N. J., Henry at Scranton, Firmstone at Glendon, Governor Porter at Harrisburg, Dr. Eckert at Reading; and, by 1846 there were about 40 anthracite furnaces in the country, distributed on the Lehigh, Hudson, Schuylkill and Susquehanna Rivers.

"In 1847 an experiment was tried at this furnace by passing a strong current of electricity through the molten iron, the battery for which consisted of 100 cells, very powerful and dangerous to handle. A heavy iron bar, with a heavy wire attached, was placed in the runner at the end of the casting-trough, and a second wire and bar were attached at the extreme lower end of the pig-bed, the current being maintained while the iron was flowing and for twenty minutes after the iron was set. This was carried on through some half dozen casts; but the men became very shy of the wires, because Jimmy Hunter, the keeper, was knocked almost senseless by using an iron bar he held in his hand to remove one of the wires which was in his way. Consequently the experiment was tried in another way. A bar of iron was suspended from the top of the furnace down into the material to a depth of some 10 or 12 feet; to this one wire was attached, and the other to one of the tuyere-pipes. The current was kept up continuously for two weeks. The samples of iron produced in this experiment were puddled, with the idea that the electric current would be found to have dispelled the phosphorus; but the result showed no apparent difference from the iron otherwise made.

"At this time, the steam-whistle was an unknown sound in the Lehigh Valley. I had secretly had made by Lehman, Sr., a brass-founder of Bethlehem, a large whistle, which measured 8 inches in diameter, and about 15 inches in depth of bell; and when No. 3 was ready, and the whistle had been attached to the boilers and they were ready to be tested, and the pressure was up to 60 or 70 pounds, I 'let her off'. The noise startled the whole town and occasioned much laughter. Mrs. Noah Davis used to tell how she and the women on Upper Church street rushed out of their houses to gather up their children, thinking, as they heard the unusual sound, that it was the last trumpet.

"As my friend of nearly half a century's standing, Mr. John Fritz, of Bethlehem, truly says in his reminiscences of the pioneer days of iron-making in this country, the active managers of the iron-works of today, possessed of all the facilities of telegraph, telephones and railroads, know little of the trials and tribulations of those arduous early times. It required three whole days to transact business between us and Philadelphia, two days to go and return by stage, and one to attend to business. When the roads were bad, it often took us twelve hours to reach the city.

"Up to 1855 our only means of transportation for coal from Mauch Chunk, and magnetic ore from New Jersey, was the canal. The hematite ores and limestone were brought to the works entirely by wagon, the country literally swarming with teams. We paid in some instances as high as $2.00 per ton for transportation on some of these ores; and not until 1855, when the Lehigh Valley Railroad was opened, and 1857, when the Catasauqua and Fogelsville line was partly finished, did we begin to have a taste of the labor-saving facilities so generally enjoyed to-day. An immense amount of labor was required simply to pile up a sufficient amount of coal to run five furnaces during the four winter months. The unloading of the coal was all done by wheelbarrows; and the accumulation of our provision commenced in the spring as soon as navigation was opened and continued until the canal was closed, since we had to store not less than 40,000 tons, in addition to what the furnaces were continually consuming. In 1847, with a view of expediting this work, we erected a large amount of trestling 25 ft. high, and a water-balance near No. 3 furnace, so that the coal could be unloaded into cars, elevated, and then dumped in this trestle-work. The first season's experience with this system was not encouraging. The rains and snows of winter caused the coal to freeze; and it would come down in great masses, often breaking the legs

of the trestles and crushing the coal, making much waste. After the second season the labor-saving apparatus was abandoned and the wheelbarrow was again resorted to."

In all of the foregoing, the chemist, of course, is conspicious by his absence. It was the steel plants with their new Bessemer converters that first felt the need of the chemist. Shortly afterward the more progressive blast furnace managers began to sense the value of the chemist in iron making. From *Chronology of Iron and Steel* by Goodale and Speer we read that in 1867:

"Thomas F. Witherbee was one of the first blast furnace managers in the United States to use the chemical laboratory in connection with the regular operation of the furnace. He started this practice when operating the Fletcherville charcoal blast furnace, about this year, near Mineville, New York."

Since about 1720 the blast furnaces had been building and operating without a chemist, not knowing what the properly trained chemist could do for them, or would do when opportunity arrived. Of this Andrew Carnegie, in his autobiography, writes in Chapter XIII, "The Age of Steel."

"In 1870 chemistry in the United States was an almost unknown agent in connection with the manufacture of pig iron. It was the agency, above all others, most needful in the manufacture of iron and steel. The blast-furnace manager of that day was usually a rude bully, generally a foreigner, who in addition to his other acquirements was able to knock down a man now and then, as a lesson to the other unruly spirits under him. He was supposed to diagnose the condition of the furnace by instinct, to possess some almost supernatural power of divination, like his congener in the country districts who was reputed to be able to locate an oil well or water supply by means of a hazel rod. He was a veritable quack doctor who applied whatever remedies occurred to him for the troubles of his patient. . . . . .

"The next step taken was to find a chemist. We found the man in a learned German, Dr. Fricke, and great secrets did the doctor open up to us. Iron stone from mines that had a high reputation was now found to contain ten, fifteen, and even twenty per cent less iron than it had been credited with. Mines that hitherto had a poor reputation we found to be now yielding superior ore. The good iron was bad and the bad was good, and everything was topsy-turvy. Nine-tenths of all the uncertainties of pig iron making were dispelled under the burning sun of chemical knowledge.

"At a most critical period, when it was necessary for the credit of the firm that the blast furnace should make its best product, it had been stopped because an exceedingly rich and pure ore had been substituted for an inferior ore—an ore which did not yield more than two-thirds of the quantity of iron of the other. The furnace had met with disaster because too much lime had been used to flux this exceptionally pure ironstone. The very superiority of the materials had involved us in serious losses.

"What fools we had been! But then there was this consolation: we were not as great fools as our competitors. It was years after we had taken chemistry to guide us that it was said by the proprietors of some other furnaces that they could not afford to employ a chemist. Had they known the truth then, they would have known that they could not afford to be without one. Looking back it seems pardonable to record that we were the first to employ a chemist at blast furnaces, something our competitors pronounced extravagant.

"The Lucy Furnace became the most profitable branch of our business because we had almost the entire monopoly of scientific management."

Some of the best known early furnaces in the country were the Colebrookdale, near what now is Pottstown, Pennsylvania, built in 1720 and named after the Colebrookdale furnace of Abram Darby in England; the Durham furnaces, built at Riegelsville, Pennsylvania, in 1727; the Warwick in 1737 also near Pottstown, Pennsylvania; the Hopewell furnace at Birdsboro, in 1759, which cast some of the cannon for Washington's army; the furnaces of the Crane Iron Works built by David Thomas in 1840, and considerably later the well-known Edgar Thompson furnaces and the Duquesne furnaces taken over by the Carnegie Steel Co., and later becoming part of the U. S. Steel Corporation. It was at the Isabella furnace that the chemist, James Gayley, worked out the experimental basis for his well-known *dry* blast process. The Bethlehem Steel Company, of course, had various furnaces in the eastern part of Pennsylvania. Furnaces had grown from the 40 or 45 ft. early height to the big furnace, which, at the Warwick plant, Edgar S. Cook first erected to a height of 100 ft., probably the usual height today, though higher ones have been tried.

(To be continued in April issue)

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Etch Pits in Iron

(Continued from page 32)

the projection to the pole is given by the estimated angle between the corresponding pit side and the surface.

A standard projection is then rotated by means of a stereographic rotation net so that the {110} poles fall on or very near to the radii and within 20° of the approximated pole positions. The orientation agreeing best with the etch pit data is chosen; in the examples of Figs. 3-6 the chosen orientations are represented by the {110} poles plotted as open circles. The solutions obtained were unique in every case, even in the example of Fig. 5 where only three traces were available. In special cases where certain auxiliary evidence is available, it is possible to determine orientations with a simpler technique, using only the directions of the traces, as was done for the determination of the orientation of ferrite in the Widmanstätten structure in slowly cooled hypoeutectoid steels.[9]

The accuracy with which the orientation of an iron crystal may be determined using the technique above described may be judged by a comparison of the solutions obtained by means of etch pits (open circles, Figs. 3-6) with the solutions by means of X-rays (black dots, Figs. 3-6); the method is sensitive to about 3°.

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[5] G. Tammann. *Zeitschrift für anorganische und allgemeine Chemie,* Vol. 148, 1925, page 293.

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[9] R. F. Mehl, C. S. Barrett & D. W. Smith. Studies upon the Widmanstätten Structure. IV.—Iron-Carbon Alloys, *American Institute of Mining & Metallurgical Engineers,* Iron and Steel Division, Preprint, February 1933.

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Faith

IN THESE days when those manufacturers who decimated their research laboratories at the onset of the depression are beginning to wonder if they are not falling behind the procession, it is interesting to note a re-affirmation of faith in research recently expressed by the General Electric Company. In a well-deserved tribute to Dr. Whitney, Mr. Rice* says:

"While it is true that the shop and the soil are great sources of wealth, the human intellect excels all, and a research laboratory is a wealth-producer *par excellence* because it is an organization of men who systematically use their brains to reach for new things, new facts, new combinations, new truths. The time will come in industry when research will be regarded as more important than advertising."—H. W. GILLETT

*E. W. Rice, Jr. A tribute to Dr. Willis R. Whitney, *General Electric Review,* Vol. 36, January 1933, pages 3-6.

F. R. Hensel

A Note on the A_3 Point of Highly Purified Iron

By F. R. HENSEL* and E. I. LARSEN*

E. I. Larsen

INTRODUCTION

SINCE the very bold paper by T. D. Yensen[1] on the A_3 point of pure iron little evidence for or against his hypothesis has been produced, and the conflict of opinion continues. Yensen assumes that the A_3 transformation is caused by carbon, oxygen, or other "stranger" atoms entering the interstitial spaces of the lattice. When the amount exceeds the solubility in α-iron for a particular temperature, the iron modifies its structure in order to accommodate the foreign atoms.

It might be true that in attacking the problem by thermodynamic methods more profit could be expected from a fundamental point of view.[2] It seemed, however, that the experimental background for theoretical considerations was not as complete as might be desired. We hope that this contribution will help to fill this need.

TEST METHODS

Dilatometric methods were used for the determination of the A_3 point. For these preliminary tests (which are to be followed by further work) the Chevenard thermal analyzer was found sufficiently accurate. In Fig. 1 a set-up for running tests under a gaseous atmosphere is shown. In the Chevenard dilatometer the expansion of the specimen (dilatation-time curve)** and that of the pyros rod (temperature-time curve) are registered simultaneousiy on the drum of its chronograph. From these 2 curves a temperature dilatation curve can be plotted if desired.[3]

*Research Laboratories, Westinghouse Electric & Manufacturing Co.

**The coefficient of expansion can be derived from the dilatation-time curve by dividing the Δ value (see Figs. 2 to 5) by the corresponding temperature value. In Fig. 5 for instance, at a temperature of 900° (heating curve Ac_3) the coefficient of expansion is $12.8 \times 10^{-3} \div 900° = 14.2 \times 10^{-6}$. This is in good agreement with the constants of pure iron given in Werkstoffhandbuch Stahl und Eisen which gives as coefficient of expansion between 0-1000° C. the value 14.5×10^{-6}. This allows also plotting a temperature-coefficient of expansion curve.

TABLE I. CHEMICAL ANALYSIS OF TEST MATERIALS

	C%	Mn%	P%	S%	Si%
Ingot Iron "as received"	.027	.02	.006	.015	.004
Vacuum-Fused Iron "as received"	.002	.002	.005	.001	.05
Hydrogen-Fused Iron "as received"	.003	.002	.002	.010	.010
Ingot Iron H_2 annealed (1400° C.)	trace	.033	.003	.012	.005
Vacuum-Fused Iron H_2 annealed at 1400° C.	trace	.002	.005	.001	.05-.17*
Hydrogen-Fused Iron H_2 annealed at 1400° C.	trace	.001	.002	.004	.009

*The high percentage (.17%) of Si in one sample was probably caused by a reduction of the SiO_2 of the crucible.

TABLE II. GAS ANALYSIS OF TEST MATERIALS

	O_2 weight %	H_2 weight %	N_2** weight %
Ingot Iron "as received"	.04-.08	nil	.004
Vacuum-Fused Iron—Type V "as received" =	.01-.08	nil	.003
Hydrogen-Fused Iron*** Type H—"as received" (forged 1100° C.)	.08	.001	.003
Ingot Iron H_2 annealed 1400° C.	0-.002	.001-.003	nil
Vacuum-Fused Iron (H_2 annealed 1400° C.)	0-.002	.001-.003	nil
Hydrogen-Fused Iron (H_2 annealed at 1400° C.)	0-.002	.001-.003	nil

**Analyses were made by Mr. N. A. Ziegler of the Westinghouse Research Laboratories by the vacuum-fusion method.

***The oxygen content of the hydrogen-fused iron Type H as melted or as forged below 900° C. is approximately .01%. This confirms the results reported by Ziegler (Preprint A.S.S.T. Meeting in Boston 1931) that above approximately 900° C. the solid solubility of FeO in Fe increases very rapidly with an increase in temperature. Apparently γ-iron can hold a greater amount of oxygen in solution than α-iron.

TEST MATERIAL

Three types of so-called "pure iron" were used in this investigation:

1. Ingot Iron.
2. Wemco Research Iron, Type V†
3. Wemco Research Iron, Type H‡

The materials were tested "as received" and after a special high-temperature anneal for 12 hours (24 hours in some cases) at 1400° C.

The analyses of the materials are reported in Tables I and II.

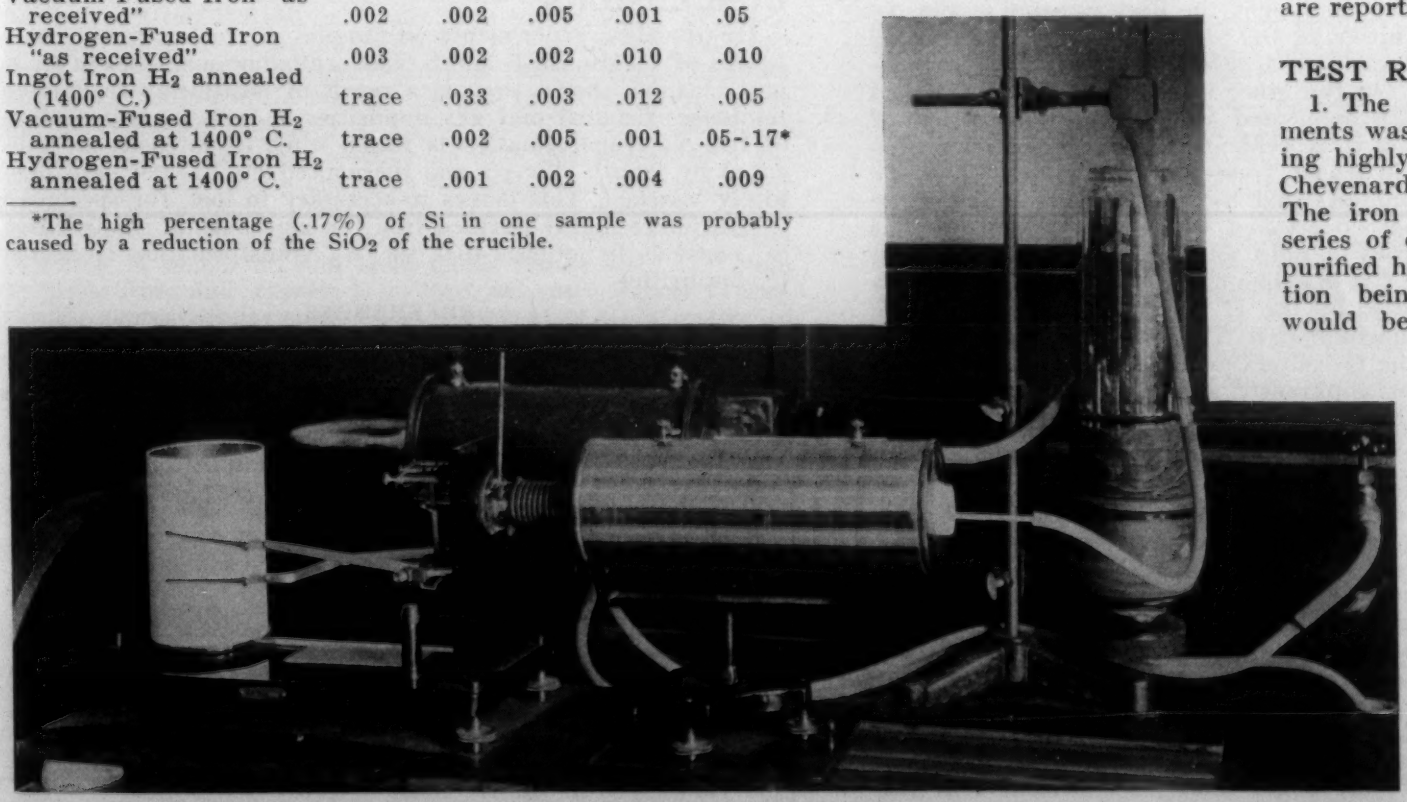


Fig. 1

TEST RESULTS

1. The first set of experiments was carried out by testing highly purified iron in the Chevenard thermal analyzer. The iron was submitted to a series of dilatation tests under purified hydrogen, the assumption being that the oxygen would be gradually removed and the cumulative effect should become noticeable. Once a cycle of tests was started the

†Material was melted in vacuo and was supplied by Mr. N. A. Ziegler of the Westinghouse Research Laboratories.

‡Material was melted under hydrogen and was supplied by Mr. A. A. Frey of the Westinghouse Research Laboratories.

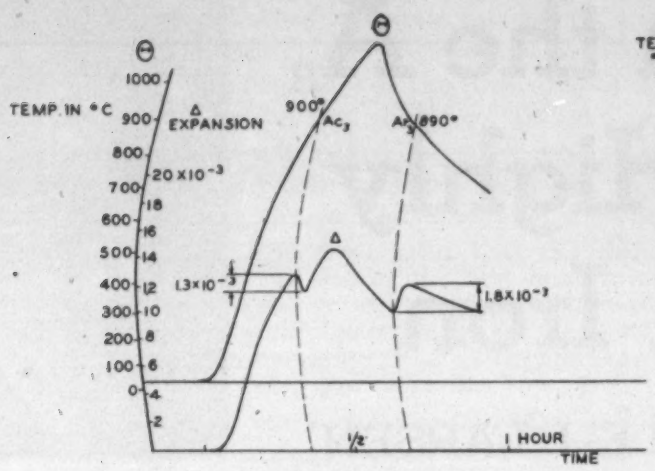


Fig. 2. Chevenard dilatation curve of ingot iron "as received" run in air atmosphere.

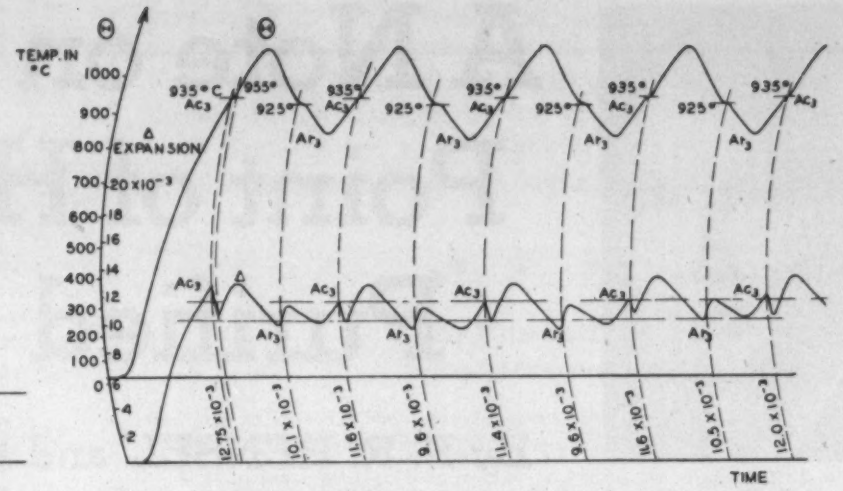


Fig. 3. Chevenard dilatation curves of ingot iron annealed 24 hrs. in hydrogen at 1400° C.

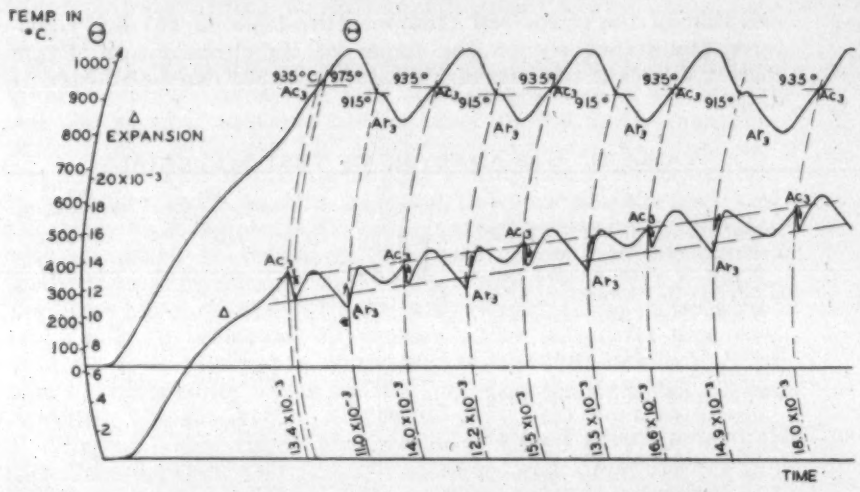


Fig. 4. Chevenard dilatation curves of Wemco research iron, type V, annealed 24 hrs. in hydrogen at 1400° C.

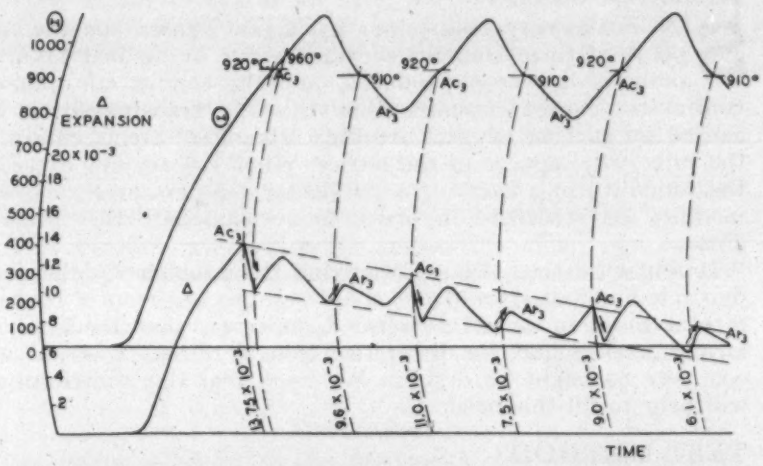


Fig. 5. Chevenard dilatation curves of Wemco research iron, type H, annealed 12 hrs. in hydrogen at 1400°C.

stream of hydrogen flowed continuously until the experiment was finished which took from one to several weeks. It was found that the continuous hydrogen treatment up to 1000° C. did not appreciably affect the temperature of or the dilatation at the A_3 point of any of the three "as received" pure irons. In Table III the results of such a testing cycle on a vacuum-fused material are recorded.

2. After annealing for 12 hours at 1400° C. in purified hydrogen the Chevenard samples exhibited certain altered dilatation effects at the A_3 point as compared to those exhibited in the "as received" state. There is no indication, however, of a disappearance of the A_3 point. The temperature of the transformation is shifted upward by 10°-30°C. A fairly sharp indentation in the temperature-time curve points to the fact that after the hydrogen treatment the heat effects[4] at the A_3 point are increased (although the opposite should be expected from Yensen's hypothesis if hydrogen has caused greater purification of the iron). On the other hand, it might be assumed that these changes are connected with a hydrogenization of the iron.[5] From Fig. 2 it is evident that no indentation was noticeable before the hydrogen treatment. The character of the thermal record also suggests that the temperature range of the transformation has been decreased which would indicate that the amount of impurities in solid solution in the iron has been lowered. From Table I it is evident that the chemical analysis was but slightly affected by the H treatment; however, some C, P and S have been eliminated. The severe hydrogen treatment has decreased the O content to traces and eliminated N almost completely, but apparently a slight amount of H has been absorbed (see Table II).

These results were confirmed by a large number of experiments.

3. Hydrogen-annealed Chevenard samples were tested in a continuous run by cooling the test specimen to just below the Ar_3 point before reheating. The results are shown in Figs. 3 to 5. In the ingot iron sample the expansion and contraction at the A_3 point remained fairly constant during the experiments. Wemco Research Iron Type H in consecutive heating and cooling cycles showed a larger contraction at the Ac_3 point than expansion at the Ar_3 point, resulting in a continuous shrinking of the test specimen. Just the opposite occurred with the Wemco Research Iron Type V, where in each new run the expansion at the Ar_3 point was larger than the contraction at the Ac_3 point, causing the sample to grow in the course of the continuous heating and cooling cycles.

TABLE III. EXPANSION DATA OF VACUUM-FUSED PURE IRON DURING A NUMBER OF CONTINUOUS RUNS UNDER HYDROGEN

Test No.	Temp. Ac_3	Temp. Ar_3	Contraction at the Ac_3 point $\times 10^{-3}$	Expansion at the Ar_3 point $\times 10^{-3}$
1	920	915	1.7	3.25(?)
2	925	920	2.0	1.95
3	918	910	2.0	.90
4	920	910	1.40	.45
5	920	907	1.3	1.1
6	935	920	1.4	1.8
7	920	915	1.5	2.0
8	915	910	1.2	1.9
9	920	915	1.7	1.5

CONCLUSIONS

Dilatometric experiments on samples of iron containing only traces of C, Mn, Si, P and S, and negligible quantities of O, N and H, have shown that as a result of treatments tending to minimize chemical and gas impurities in iron the temperature of the A_3 transformation is raised while its intensity as indicated by length changes and thermal effects has not been definitely lessened. This makes it necessary to look for specimens of still more highly purified iron for experimental confirmation of Yensen's hypothesis that the A_3 transformation is caused by impurities.

REFERENCES

[1]"Pure Iron and Allotropic Transformations," *American Institute of Mining & Metallurgical Engineers, Iron & Steel Division Transactions*, 1929, pages 320-349.

[2]See H. Schenck. Physikalische Chemie der Eisenhüttenprozesse. Vol. 1, page 119. "On account of the higher atomic heats of the γ-iron at lower temperatures its free energy becomes smaller than that of α-iron at a temperature of approximately 906° C. and the transformation α to γ-iron results. At still higher temperatures, however, the temperature coefficient of the free energy of α-iron exceeds that of γ-iron and the transformation is reversed again at 1401° C.

It is obvious that these temperature curves of the free energy can be changed by adding alloying elements in such a way that their intersection and therewith the transformation α to γ to δ is eliminated entirely. This is the case in iron alloy systems with a closed gamma loop."

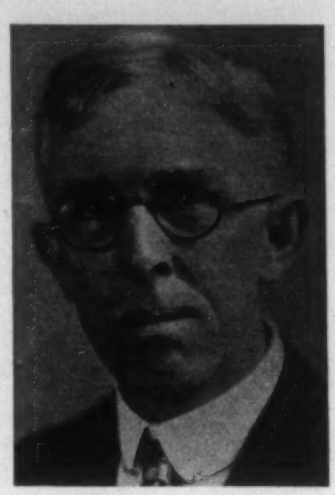
[3]For a detailed description of the apparatus see: P. Chevenard "Analyse Dilatometrique des Materiaux." Dunod, Paris, 1929.

[4]H. Klinkhardt (*Annalen der Physik*, Vol. 84, 1927, page 167) gives as heat of transformation of "pure iron" from alpha to gamma structure 215.5 cal per gram atom of iron. Other investigators report figures as high as 380 cal. (H. Schenck. Physikalische Chemie der Eisenhüttenprozesse, Erster Band, Berlin, 1932, page 118.)

[5]P. P. Cioffi. *Bell Laboratories Record*, Vol. 10. No. 5, Jan. 1932, page 159.

Corrosion-fatigue of Metals*

By H. F. MOORE**



THE lecture of Dr. Gough is a summary of our present day knowledge of the phenomena of the simultaneous action of corrosion and cyclic stress. It is in itself a summary of a vast amount of published data, including Gough's own investigations. This abstract of such a summary is necessarily confined to a statement of Dr. Gough's conclusions and statements of theory, and cannot go into detail as to his authority for his statements. It is hoped that this abstract will lead many readers of METALS & ALLOYS to read Dr. Gough's article in full, and as many of the numerous references as is possible. The present abstractor is greatly impressed with the value of Dr. Gough's lecture, and wishes to call attention to the care with which he has given credit for work done by others, and to the valuable list of references he has compiled.

Dr. Gough defines "fatigue" of metals as including all physical changes which occur in metals on account of cycles of repeated stress—a definition differing from general American practice, which limits the term "fatigue" to the phenomenon of a spreading fracture under repeated stress. He distinguishes between "reversed" stress, "alternating stress," "repeated" stress, and "pulsating" or "fluctuating" stress—a distinction which might well be followed carefully by all writers on "Fatigue of Metals."

He uses the term coined by McAdam "corrosion-fatigue limit," although he is not satisfied with it, and modifies it by writing it "corrosion-fatigue limit (N)," inserting for "N" the maximum number of cycles reached in a series of tests.

Gough's picture of the process of corrosion-fatigue resembles McAdam's in that it comprises a corrosion stage, in which stress plays little part but in which pits are formed on the surface of metal. A second "fatigue" stage then occurs; these pits then become points of localized high stress—"stress raisers" Gillet has named them—and under continued cycles of stress a fatigue crack starts and spreads from one or more of them. The protective film of corrosion products formed over the surface, and ability of this film to resist the deformations incident to repeated stress are very important factors in determining resistance to corrosion-fatigue.

A considerable amount of metallographic data is studied to throw light on the details of the progress of corrosion-fatigue damage in metals. After the "fatigue" stage is started the crack is nearly always trans-crystalline. An exception is noted in the case of lead, which shows spreading intercrystalline cracks both in corrosion fatigue and under ordinary fatigue tests in air. One micrograph of steel, taken by Ludwik, is of especial interest. The crack was caught at such an early stage of its development that only one crystalline grain is cracked, and the crack is entirely *within* the grain. The experimental evidence now available seems to indicate clearly that in the "fatigue" stage of a corrosion-fatigue failure a fatigue crack spreads very much as it does in metal subjected to cyclic stress under non-corrosive conditions.

The present abstractor would note that this spread of a fatigue crack seems to be distinctly different from the spread of intercrystalline cracks observed under the phenomenon known as "caustic embrittlement," and from the intercrystalline cracks observed in aluminum and steel under steady load and high temperatures, and observed in lead at room temperatures. Gough quotes results obtained by Betty at the University of Illinois showing that under the corrosive influence of water which had been chemically treated so as to prevent "caustic embrittlement" corrosion fatigue took place in boiler steel.

Gough gives some summaries and conclusions from the large amount of test data available—mainly from McAdam—and brings out some general conclusions as to the strength of metals under corrosion-fatigue conditions. He believes that there is some reason to doubt the existence of a true corrosion-fatigue limit, a limit below which an *indefinitely large* number of cycles of stress can be resisted under the action of a corroding medium. In this he agrees with McAdam. Another point on which Gough and McAdam agree is that in corrosion-fatigue tests not only must number of cycles of stress be considered, but also the *time* which elapses under corrosive action. Possibly this time element plays some part in ordinary fatigue tests in air, but nowhere nearly as important a part as in corrosion-fatigue tests. Gough notes that for plain carbon steels and for ordinary alloy steels heat treatment, increased carbon content, and cold working do not appreciably increase the corrosion-fatigue limit although they may markedly increase the fatigue limit in air. He notes contradictory results of corrosion-fatigue tests on iron with a small copper content. He notes that for corrosion-resistant steels the corrosion-fatigue limit is distinctly below the fatigue limit in air, but that the difference between the two limits is much less than for plain carbon or ordinary alloy steel. In these "stainless" steels the chromium content seems to be the most effective factor, but the nickel content is also important.

In noting test results for corrosion-fatigue tests of copper-nickel alloys, copper-zinc alloys, and light aluminum alloys it seems that heat treatment is ineffective in raising the corrosion-fatigue limit above that of the air-fatigue limit.

In general the resistance of a metal to corrosion-fatigue depends on its resistance to *corrosion in a particular environment.* The maximum resistance to corrosion-fatigue is developed when a metal is in the most favorable condition to resist *corrosion.* Improvement of the resistance of a metal to corrosion-fatigue by means of heat treatment or cold working is very doubtful; improvement is possible by a change in chemical composition which gives increased resistance to corrosion under a particular environment.

Gough has plotted results of corrosion-fatigue test data on three-dimension models, whose coordinates are stress range, time, and number of cycles. He makes use of McAdam's terms "total damage" and "net damage." Total damage is the percentage reduction from the air-fatigue limit to the fatigue limit found by fatigue tests of specimens which have been subjected to some definite routine of corrosion-fatigue. The net damage is the percentage reduction from the fatigue limit of metal subjected to some definite period of *stressless* corrosion to the fatigue limit of specimens which have been subjected to some definite routine of corrosion-fatigue. Gough in his article gives photographs of some of his three-dimensional models.

From McAdam's data the following tentative relation between stress range and average rate of net damage is given.

$$R = CS^n$$

In which R = rate of net damage in percent per day.
S = stress range in lbs./in.^{2}
C and n are experimental constants.

Gough quotes from McAdam's results values of n varying from 2.6 to 5.7.

Gough notes the report from German investigators that there seems to be some degree of correlation between notch-sensitiveness of a metal and its resistance to corrosion-fatigue.

The effect of time on corrosion fatigue is summarized by the conclusion from test results that at low frequencies of stress-cycles the rate of *net* damage is nearly proportional to the frequency; at high frequencies of stress-cycles the rate of net damage is nearly independent of the frequency.

The present abstractor of Gough's article would note that very little data indeed are available on corrosion-fatigue under cycles of stress other than those involving complete reversal of stress. He would report a few fatigue tests of structural steel at the University of Illinois under cycles of stress varying from zero to a maximum, in which the ratio of corrosion-fatigue limit to air-fatigue limit was of the order of magnitude of the ratios found under cycles of reversed stress.

An important part of Gough's paper concerns itself with the effect of the environment on the corrosion-fatigue resistance of a metal. He gives especial attention to the possible effects of corrosion-fatigue in air, in hydrogen and in steam. Tests have been reported which show a higher fatigue limit for copper under a stream of water than for copper in air. It is suggested that air corrosion may be appreciable in copper. The abstractor would note that the possibility of appreciable air corrosion of duralumin has been suggested as an explanation of the fact

*H. J. Gough. Corrosion Fatigue of Metals. Eleventh Autumn Lecture, Institute of Metals, Journal Institute of Metals, Vol. 49, No. 2, 1932, page 17.

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that in air-fatigue tests no absolute endurance limit of duralumin has been found. Gough points out that apparently in any corrosion-fatigue test the presence of *oxygen* is very important. He notes Lehmann's tests at Oxford which showed that a specimen immersed in a quiet corroding solution gave a much smaller corrosion-fatigue effect than is found when the corroding solution is squirted on the specimen in a thin stream or spray. Gough also notes Binnie's test in which the corrosion-fatigue effect was found to be less when an atmosphere of very pure hydrogen surrounded the jet than when air was the surrounding gas. He notes that in the tests of copper, made by McAdam, in which the corrosion-fatigue limit was higher than the air-fatigue limit, McAdam used various protective coatings — grease, paraffin, lacquer, varnish — to protect his air-fatigue specimens, but Gough feels that these coatings, while practically impermeable to water, may have been permeable to air. Gough summarizes experiments of Haigh and Jones on the corrosion-fatigue of lead. While tests were not carried far enough to determine corrosion-fatigue limits the corrosion-fatigue failure seemed to be "delayed" in air as compared with its occurrence under acetic acid, which caused nascent hydrogen to be generated, and, presumably, thus neutralized the effect of any oxygen present. Gough says of the tests of Haigh and Jones, "They suggest strongly that (1) oxygen is a factor in the normal process of the fatigue of lead and some lead alloys, (2) that as the available oxygen supply to the specimen surfaces is reduced, the endurance of the specimens is improved, (3) that the beneficial effect produced on the fatigue resistance by reducing oxygen more than outweighs the destructive effects brought about by roughening the surface of the specimen by acid corrosion."

Gough's paper discusses tests by Fuller and by Honneger on corrosion-fatigue of steel in steam. He notes that Fuller found as bad effects of corrosion-fatigue from a jet of wet steam as from a jet of carbonate water, and that a somewhat less effect from wet steam was found in tests at the University of Illinois. The present abstractor would note that the Illinois tests were made in an *atmosphere* of wet steam rather than in a jet of wet steam. Honneger's test results are summarized in the accompanying table.

Condition	Fatigue Limit lbs./in.^{2} (2×10^8) Limits	Average
In air In air (chromium plated) In hot water at 100° C. In air; specimen covered with film of oil	46,000-40,000	43,000
In atmosphere of dry saturated steam at 100° C.	34,000-26,000	30,000
In atmosphere of dry saturated steam at 100° C. (chromium plated)	32,000-23,000	27,500
In water stream	23,000-18,000	20,500
In water stream (chromium plated)	25,000	25,000

Discussing the theory of the origin of corrosion pits in the first stage of corrosion-fatigue, Gough concludes, "that the various causes of non-uniformity within the metal are capable of setting up electrochemical actions, but of such a small order as are not likely to produce the gross damage often observed in corrosion-fatigue. We also deduce that corrosion is not likely to be accelerated by the presence of elastic strain." However, corrosion *is* likely to be accelerated by the presence of *plastic* strain, and it seems quite probable that selective corrosion takes place along the planes where slip bands have formed. Frequently such slip bands form in a number of isolated crystalline grains before a tension test would show evidence of any "elastic limit." This explains the spacing of initial corrosion pits at intervals farther apart than the width of a crystalline grain.

Gough gives quite an extensive discussion to the "Evans-Aston" and the "Bengough" hypotheses as to the mechanism of the penetration of corrosive action into the metal from the bottoms of corrosion pits. As the present abstractor understands it, the Evans-Aston hypothesis holds that the clogging of a corrosion pit with products of corrosion prevents the penetration of oxygen enough to form a tough protective film there; and the pit tends to deepen. According to the Bengough hypothesis the tendency for a corrosion pit to deepen is not because it receives too little oxygen, but because it receives too much. Quoting from Gough's paper, "According to Bengough the surface of the metal surrounding the pit is less susceptible to corrosion, is probably covered with a wholly or partly protective film, and the oxygen in its neighborhood becomes available to the pit; the corrosion products offer negligible resistance to the passage of oxygen to the base of the pit, and corrosion proceeds." Gough also mentions McAdam's hypothesis, although he seems to regard both the Evans-Aston and the Bengough as more satisfactory, and quotes McAdam to the effect that the fact that greater damage is done by simultaneous action of cyclic stress and corrosion than by stressless corrosion "seems to indicate that the effective solution pressure is higher in a specimen under cyclic stress than in a specimen not under stress. This increase in effective solution pressure may be due in part to the removal of a protective film."

The importance of the surface film formed by corrosion is strongly emphasized by Gough; he says "corrosion-fatigue phenomena are incomprehensible unless the problem is considered from the aspect of the formation and stability, repair, penetration by diffusion, or breakdown of surface films. Also the essential differences between stressless corrosion and corrosion-fatigue are difficult to reconcile until the effect of cyclic strain on the film is considered."

Gough points out that the protective films formed by corroding agents cannot carry any appreciable amount of stress, but that their ability to withstand considerable *deformation* (strain) without cracking or becoming permeable to the passage of corroding agents is of great importance. The fact that the corrosion film formed is tough is probably the principal reason for the great resistance to corrosion (either stressless corrosion, or, to a less degree, to corrosion-fatigue) of the high-chromium (stainless) irons and steels. Furthermore, the successful use of chemical "inhibitors" which cause quick "repair" of a cracked or permeable film (by general surface oxydation) is noted by Gough, with especial reference to the work of Speller, McCorkle, and Mumma at the laboratories of the National (U.S.) Tube Company. They used sodium dichromate (a strong oxydizing agent) in the water sprayed on the specimens, and found that it was an almost perfect "inhibitor" of damage due to corrosion-fatigue. Their work also emphasized the importance of small *local* differences of condition, the effect of which may be far more destructive than the effect of the general environment.

A section of Gough's paper is given over to the discussion of corrosion-fatigue failures in service, and a considerable number of interesting photographs are shown. Gough reports corrosion-fatigue failures in service have occurred in: marine propeller shafts, ship's rudder main piece, steering hubs and stub axles of automobiles, boiler and superheater tubes, turbine rotors, discs, and blading, street car and locomotive springs, piping conveying corrosive liquids, flying wires of airplanes, pump shafts, pump rods, pump bodies, water-cooled piston rods of Diesel engines; and steel railway sleepers. Gough feels that the occurrence of corrosion-fatigue in marine boilers has not yet been definitely proven, differing in this opinion from McAdam. In the service failures studied the exposed surfaces have in some cases suffered appreciable damage by general corrosion, but the reduction of dimensions by corrosion is quite insufficient to explain the great reduction of strength. Corrosion-fatigue depends on *localized* action.

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